ELECTRICITY IN MODERN LIFE

BY

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NEW YORK
P. F. COLLIER & SON
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PREFACE

IN THIS little volume I have endeavored to give a brief but intelligible and connected sketch of the more important of the numerous useful functions fulfilled by Electricity in modern daily life, the scientific principles underlying these practical applications, and the history of their development.

It is addressed primarily to readers who have no previous knowledge of the subject, but who wish to know something of what Electricity has been made to do for us, and of how it has been made to do it. I trust, however, that it may also be of some use to students who are just beginning the study of practical Electricity, by giving them a general view of the field of knowledge which they will afterward have to study in detail.

I have to thank my friend, Professor Sylvanus P. Thompson, and his publishers, Messrs. Spon, for permission to use his excellent series of skeleton diagrams illustrating the principles of dynamo construction and regulation, together with some other illustrations from his "Dynamo-Electric Machinery," a most valuable work, which every electrical engineering student should not only obtain, but carefully study. I am also indebted to Professor Thompson and his publishers for the illustrations of Reis's Telephone, which are taken from his book on the subject.

My friend, Mr. Preece, and his publishers, Messrs. Longmans, and Messrs. Whitaker, have laid me under great obligations by their permission to make free use of the

illustrations in Preece and Sivewright's standard work on Telegraphy, and in Preece and Maier's recently published volume on the Telephone.

I also have to express my thanks to the editors and publishers of "The Electrician" and "Engineering" for the use of illustrations, and to Messrs. Crosby, Lockwood & Co. for some illustrations which I have taken from Sabine's valuable historical work on the Electric Telegraph.

In tracing the history of the telegraph and of submarine telegraphy I have been much indebted to Mr. J. J. Fahie's "History of Electric Telegraphy," which first appeared in the pages of "The Electrician," and to Wünschendorff's "Traité de Télégraphie Sous-Marine," the best work on Submarine Telegraphy which has yet been published. Lastly, I have to thank my brother, E. W. de Tunzelmann, M.B., for contributing the chapter on Medical Electricity.

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65 LONGRIDGE ROAD,
SOUTH KENSINGTON,
October 30, 1889.

ELECTRICITY IN MODERN LIFE

CHAPTER I

WHAT WE KNOW ABOUT ELECTRICITY

IT WOULD be of the greatest interest to trace the progress of our knowledge of electrical phenomena from the early time when the Greek philosopher Thales first observed that a piece of amber rubbed with various substances was capable of attracting light objects, but the story would demand a volume to itself. [I will try, therefore, to set forth, as briefly as possible, the present state of our knowledge of the nature of electrical phenomena and of the means by which electrical actions may be produced.]

If a dry glass rod is rubbed with one of sealing-wax or resin, and the rods are hung up by threads so that they can move freely, they will be found to attract each other; but if two rods of resin rubbed with glass, or of glass rubbed with resin, are hung up near together they will repel each other.

The rods are then said to be electrified, and as they exhibit two distinct phenomena—namely, attraction and repulsion—we see that there are two distinct kinds of electrification.

If the rods are laid aside for a short time they will be found to have lost their power of attracting or repelling each other. These phenomena may be shown still more

clearly by rubbing the rods with silk, when it will be found that two similarly rubbed rods will repel each other and two dissimilarly rubbed rods will attract each other. The electrification of glass rubbed with silk is known as vitreous electrification, and that of resin rubbed with silk as resinous electrification.

The ordinary cylinder or plate electrical machines are simply convenient devices for rubbing a glass plate or cylinder with silk or other suitable substance in such a manner as to obtain electrification in a comparatively large quantity. The electricity, as it is obtained from such a machine, is allowed to pass to a cylinder of brass supported upon glass legs, usually known as the prime conductor, and after the machine has been in action for a short time, it will be found that on bringing the finger to the prime conductor a spark will pass. If before trying this experiment the prime conductor is connected with the ground by a wire or chain, no spark will be obtained. The reason for this is that the electrification produced upon the prime conductor is not able to pass through the glass, but passes away as rapidly as it was produced through the wire or chain. This shows that some substances will allow electricity to pass through them with facility; such substances are called good conductors. Other substances only allow electricity to pass with great difficulty, and they are called bad conductors or insulators. The best conductors known are metallic bodies.

Dry silk is a bad conductor of electricity, and therefore a conductor suspended by a dry silk thread will retain its electrification for a considerable time. Resin, and glass free from lead, are even worse conductors, or, in other words, better insulators than silk, and are therefore commonly used in making insulating stands for electrical apparatus. They

must be kept dry, for if a film of moisture is allowed to form upon their surfaces this film will carry away the electrification. Air and other gases are absolutely perfect insulators. A simple and convenient instrument for detecting electrification consists of a small pith-ball suspended from a support by means of a dry silk thread. If an electrified body is brought near to such a ball it will attract it, but when it comes into contact with the charged body the ball will take a portion of its charge and will be immediately repelled. Such an instrument, being capable of indicating the existence of electrification, is called an electroscope,

Take a rod of resin or sealing-wax, and have a small flannel cap made to fit exactly over the end of the rod, and having attached to it a dry silk thread. Now place the cap upon the end of the rod and turn it round several times so as to rub it against the rod, and then bring the rod and the cap together to the suspended pith-ball—it will have no effect whatever upon the ball; but if the flannel cap is removed by means of the silk thread and brought near to the pith-ball it will attract the ball just as the charged conductor did, and after the ball has touched the flannel it will be repelled. If the rod which was rubbed with the flannel is then held near the pith-ball, the ball which was before repelled will be attracted.

Now I will suppose that the reader has no further knowledge of what electrification consists in than has been furnished by the foregoing experiments, and I will ask him to consider what information they can give concerning its nature. What has been proved is that no electricity is actually generated, for the electrifications of the two bodies are equal in amount, but opposite in sign.

Imagine for a moment that electrifying a body positively

consists in adding a certain something to it, then electrifying it negatively to the same extent will simply mean taking away an equal amount of that something from it. At this stage an analogy will be of assistance, for the great difficulty of forming exact conceptions of electrical action lies in the fact that we have no electrical sense. We are able, by means of our ordinary senses, to detect the presence, or the transference from one place to another, of solids, liquids, or gases. Our senses again will tell us when one body is hotter than another; but we have no corresponding means of directly determining whether one conductor is more or less highly charged with electricity than another. Consider, then, what happens when a liquid—such as water, for example—is poured from one vessel into another. If we have a certain quantity of water contained in two vessels, we may pour water from one into the other; but the exact amount poured into one must be taken out of the other, always supposing that no water is brought in from outside, and that no loss takes place of the total amount in the two vessels.

Now carry the analogy a step further. Suppose the water to be at the same level in the two vessels, and suppose we have the means of connecting the two by a tube, by which water can be driven from one into the other. To do this, suppose the vessels to be cylinders, and suppose that a piston fits air-tight into each cylinder, and floats upon the water contained in it. Imagine that the vessels are opaque, so that we cannot see what goes on inside them; but assume that we have the means of forcing down one of the pistons, so as to drive the water into the other vessel. Let the space above the piston in each cylinder be occupied by air, and let a tube with a narrow opening be fitted into the top of each cylinder. Now let the pair of cylinders be given to some one

who is ignorant of what they contain, and ask him to work the mechanism for depressing the piston. Suppose, moreover, that he does not know which piston is depressed by the mechanism. He will have no direct means of observing the amount of water inside; but if he allows some light objects, such as pieces of tissue paper, to fall near the ends of the two projecting tubes, he will find that the paper is attracted toward one tube and repelled from the other—the reason, of which he knows nothing, being that the water, which is forced into one cylinder, drives out the air above it through its tube, while the descent of the piston in the other cylinder allows air to rush in through its tube. He will therefore find two different effects produced—namely, attraction of the paper to one tube, and its repulsion from the other. If now he takes a tube of the form of the letter "Y," and connects the two arms by means of India-rubber tubes with the tubes issuing from the two cylinders, he will find that pieces of paper placed near the stem of the "Y" tube will neither be attracted nor repelled, the reason of course being that the amount of air sucked into one cylinder is equal to the amount driven out of the other, so that no air is either driven out of the stem of the "Y" tube or sucked into it. We must suppose that the experimenter is only able to observe the attraction of the paper to one tube and its repulsion from the other, and that he has no means of finding out that these are caused by the expulsion of the air from one tube and by its being sucked into the other. He will therefore have exactly similar data to those obtained from the electrical experiments, and he will draw the conclusion that the effect of working the mechanism is to cause the two cylinders to give rise to two distinct effects, but that the sum total of the two actions is zero. This analogy

will help to explain how it is that though we know absolutely nothing of what electricity really is, yet we are entitled to assert that, when electrification takes place, something occurs like the transference of an incompressible liquid from one place to another.

In the application of electricity to practical purposes what is required is either to maintain a continuous flow of electricity through a conductor, or to make it surge repeatedly backward and forward through the conductor. It is therefore necessary to consider the means by which electricity can be set in motion. Take a metallic cylinder resting horizontally upon an insulating stand, and from each end of it suspend by means of a thread a pair of pith-balls. Then bring one end of the cylinder near to a conductor charged with, say, positive electricity, and it will be found that the pith-balls will immediately diverge from each other. Now rub a piece of sealing-wax with some silk, and, keeping the charged conductor near the end of the insulated cylinder, bring the sealing-wax near to each pair of balls in succession, when it will be found that the pair nearest to the conductor will be repelled from it, showing that the nearer end of the cylinder with the balls suspended from it are negatively electrified. The pair at the other end of the cylinder will be found to be attracted, showing that the further end is positively electrified. The effect of bringing the insulated cylinder near to the positively charged conductor has, therefore, been to charge its further extremity positively and its nearer extremity negatively, so that a positively charged body not only repels a similarly charged body, but it also drives electricity, of a similar kind, to the further portion of the conductor into the neighborhood of which it is brought. This is called electrical induction.

Consider the question of electrical induction somewhat further. Take a cylindrical glass jar, and coat it, both inside and outside, to within two or three inches of the top with tin-foil. Then place the jar upon an insulating stand, and connect, by means of a wire or chain, one of the tin-foil coatings—say, the inner one—with the conductor of an electrical machine, and work the machine for a short time. We should then expect the coating in connection with the conductor of the machine to have received a charge from the latter. If the jar is disconnected from the conductor we should therefore expect, on presenting a finger to the inside coating, to receive a spark. If the jar is thoroughly dry at the time of making the experiment, so that the inner coating is well insulated, a small spark will be obtained if the machine was acting properly; but it will be a very feeble one. Now repeat the same experiment, having previously connected the outer coating with the earth. It will then be found that after turning the machine as many times as before a very much stronger spark will be obtained on presenting a finger to the inner coating, thereby connecting it, through the observer's body and the earth, with the outer coating; and indeed, if the jar is a large one, and the machine is in good condition, the strength of the spark will probably be such as to prevent any desire for a repetition of the experiment.

Now, what is it that has taken place, and what is the cause of the difference in the two cases? The fluid analogy will here again be of assistance. A conductor will be represented by a tube; and an insulator, or, as Faraday called it, a dielectric, by a partition across the tube, which will not allow water to flow through it, but of such a nature, however, that the water upon one side of the division may be

capable of acting upon the water at the other side. The latter condition is necessary in order to represent the electrical actions, for it has been pointed out that when a charged body is brought near to a conductor, but is separated from it by a dielectric, such as air, for example, the electricity similar to that on the charged body is driven to the further portion of the conductor.

Suppose, therefore, that the tin-foil coatings of the jars are represented by two tubes, while the dielectric, glass, is represented by a division, consisting of a sheet of some elastic substance—for example, a thin sheet of India-rubber. The opposed surfaces of the tin-foil coatings are separated by means of the glass of the jar, and one of the non-opposed surfaces is in contact with the dielectric, air, while the other is connected with the conductor of the electrical machine. The state of things in the first experiment may therefore be represented by closing up the end of one of the tubes with a second sheet of India-rubber, attaching a pump to the other tube and forcing water into it. The India-rubber separating the two tubes, and that which closes the end of the tube furthest from the pump, will stretch slightly, and therefore a small quantity of water can be forced in, and if the tube connected with the pump is suddenly opened the India-rubber division will fly back to its original position, and throw out the water just as the inner coating was discharged when touched with the finger

In the second experiment the outer coating of tin-foil was in connection with the earth. Now, in order that the electrical machine may continue to give a supply of electricity, its rubber must be in connection with the earth; or the jar may be insulated and its outer coating connected with the rubber of the machine, the inner coating remaining

in electrical connection with the prime conductor. To represent the state of things in the second experiment the India-rubber covering must therefore be removed from the further extremity of the tube, and the tube allowed to dip into a tank with which the pump is also in connection; or the tube representing the outer coating of the jar may be connected directly with the pump. In either case, when the pump is worked, water will be forced into the tube representing the inner coating, the same amount being simultaneously withdrawn from the other tube; and if sufficient force is applied, this may be continued until the India-rubber division breaks. Similarly, in case of the jar, given a sufficiently powerful machine, the electrification may be increased until the electricity either overflows or discharges through the glass, which would be broken in the process. If the jar is properly constructed, the tin-foil will be taken up so near to the edge that the discharge when it takes place will occur through the air, round the edge of the jar instead of through the glass, thereby saving the jar from destruction.

This experiment illustrates something more than the previous ones—viz., it not only shows that the flow of electricity is like the flow of a liquid, but that it is like the flow of an incompressible liquid; so that in order to force electricity into any conductor an equal amount must be simultaneously forced out of it. If this explanation of the action of a Leyden jar is correct, we should expect the glass, or other dielectric, separating two charged conductors, to be in a state of constraint, and this has been conclusively proved to be the case by examining the glass by the aid of polarized light.

We are therefore justified in concluding that whatever electricity really is, it behaves exactly as if it were an incom-

pressible liquid; and it follows that the first analogy for the production of electricity by friction between two conductors would have been more exact if we had supposed the space above the pistons in the jars to be likewise filled with water, and the whole apparatus to be immersed in a tank of water, when, of course, instead of air flowing out of one tube into the other, we should have water, and the phenomena might be made evident by the aid of some light bodies suspended in the water near the open ends of the tubes. Water may be forced through the tube in various ways; but, other circumstances being the same, the strength of the current of water—that is to say, the quantity which passes across a section of the tube in unit time—will depend upon the pressure, as will also the height to which the water can be forced. Again, if the vessels containing water are in connection by means of a tube, no flow will take place through the tube if the water is at the same level in both vessels; but if it is at a higher level in the first than in the second, the water will flow along the tube from the first vessel into the second until the levels become equal, because, as long as the level of water in the two vessels remains unequal, the pressure from the first vessel to the second will be greater than in the opposite direction. Since the flow of electricity may be compared to the flow of water, we should expect to find something analogous to difference of pressure as the cause of the flow of electricity from one conductor to another. This has already been found to be the case in charging a Leyden jar by means of an electrical machine, what may be called electrical pressure gradually increasing up to a certain limit with the number of turns given to the machine; and with a large machine and a small jar the jar might be broken, or, if properly constructed, made to overflow.

With a small machine and a large jar, however, it would be found that after a certain number of turns no further effect whatever would be produced, showing that the limit of pressure attainable by means of the machine has been reached. This introduces the idea of what is called electrical potential. The difference of potential between two conductors, or between parts of the same conductor, is analogous to difference of pressure, due to difference of level in the case of water; and indeed electrical engineers very commonly use the term electrical pressure in place of potential difference.

Now, water can only flow from one part of a vessel to another when the pressures in different directions are unequal; but this difference of pressure may be produced in other ways than by difference of level. In the same way the flow of electricity may be produced by other means than difference of potential, and therefore the more general term, electro-motive force, usually denoted by the letters E.M.F., is employed, being defined as whatever causes motion of electricity. Potential difference is therefore a special way of producing E.M.F., just as difference of level is a special way of producing difference of pressure in the case of water.

It must not be forgotten that it was originally decided to call vitreous electricity positive, and by flow of electricity to denote a flow of positive electricity—that is to say, using the water analogy, we suppose positive electrification to consist in an excess of water. The assumption that negative electrification consists in an excess of water might equally well be made, for although it has been shown that something analogous to a flow of water takes place in a conductor which is undergoing changes in electrification, no criterion has been obtained to determine the direction of the flow,

which is absolutely unknown, and we are totally ignorant also of the velocity of flow, which may, for all we know, be a million miles in a second, or half an inch in a century

Friction between different substances is not at all a convenient method for obtaining an electric current through a conductor, for even when a very large frictional machine is used only very weak currents can be obtained. The most convenient method of producing a current for ordinary experimental purposes is by means of some form of galvanic or voltaic cell—a convenient form of cell for obtaining fairly strong currents for a short time is the well-known Bichromate cell. It consists of a glass vessel containing a solution of bichromate of potash, with a slight trace of sulphuric acid, and a plate of zinc and one of carbon, or more frequently two plates of carbon, one on each side of the zinc, immersed in the solution. If the carbon plates or plate are then connected with one end of a wire or other conductor, while the other end of the conductor is connected with the zinc plate, a current of positive electricity will flow from the carbon through the wire to the zinc, and through the liquid from the zinc to the carbon. A single cell of this kind holding about a quart of solution is capable of maintaining the light of a small incandescent lamp for some three or four hours. If several of these cells are joined together by connecting the carbon of one to the zinc of the next, and so on, the arrangement is called a galvanic or voltaic battery. If the reader has a battery, say of four or five such cells, and a frictional machine at command, he will find it interesting to compare the current obtained from the battery with that produced by the frictional electrical machine. If the rubber and the prime conductor of the machine are connected together by means of a piece of fine platinum or iron wire

a few inches in length, no effect whatever will be observed; but if the same wire is used to connect the last two zinc and carbon plates of the battery, it will be raised to a white heat. Now, a current of electricity, when passing through a wire or other conductor, always develops heat, and the reason that no heat is observed in the wire connecting the conductor and the electrical machine is simply because the quantity of electricity passing is too small to produce any perceptible effect.

If now two copper wires are connected to the free zinc and carbon of the battery, and their ends brought together, a small spark will be seen when they come in contact. The length of this spark will be so short that it would be impossible to measure it, while with an electrical machine of moderate size there would be no difficulty in obtaining a spark several inches in length.

If, again, the inner and outer coatings of a Leyden jar are connected with the rubber and prime conductor of the machine, and the handle is turned for some time, the jar will either burst or overflow if the machine is powerful enough, and if not, a strong spark will be obtained from the jar on connecting its inner and outer coatings. If the ends of the wires from the battery are now connected with the inner and outer coatings of such a jar, it will be found that however long the battery may be left on, the jar will not overflow, nor will it be possible to get a perceptible spark on connecting its two coatings. What is required in order to charge a Leyden jar is not so much a large quantity of electricity as a high pressure, to use the language of an engineer, or a high potential difference, if we wish to speak scientifically. The electrical machine gives a high potential difference but a very small current, while the battery gives a very much

larger current with a much smaller difference of potential, or lower pressure; indeed, it would be necessary to employ a battery of many thousand cells in order to get a potential difference equal to that produced by even a small frictional machine.

CHAPTER II

WHAT WE KNOW ABOUT MAGNETISM

IT has been known since very early times that a certain mineral, commonly called lodestone, possesses two very remarkable properties. In the first place, it has the power of attracting iron, and in a lesser degree some other substances—more especially the two metals, nickel and cobalt—with a force which is greater beyond all comparison than the attraction of gravitation, which is always exerted between two portions of matter. In the second place, when a portion of it is suspended, so that it can turn freely in any direction—for example, if it is hung up by a thread passing through its centre of gravity—it always assumes a certain definite direction at a given place on the earth's surface. These properties may be communicated to pieces of iron or steel by simply rubbing them in a certain definite manner with a piece of lodestone. In the case of very soft iron, however, the properties so communicated are very soon lost again.

Any substance which has these properties is called a magnet, and the action of communicating this property to iron is called magnetizing it. The lodestone is a chemical compound of the metal iron with the gas oxygen, and on account of its possessing the two properties mentioned it

is also known as magnetic iron ore, or magnetic oxide of iron.

Humboldt, in the "Cosmos," tells us that three centuries before the Christian era the Chinese caravans were guided on their journeys across the trackless wastes of Tartary by means of a little human figure revolving upon a pivot, and holding in its outstretched hand a fragment of lodestone, so placed that its arm always pointed to the south.

Large magnets are not now manufactured by rubbing iron with lodestone, because, as explained in a later chapter, the electric current provides a means of magnetizing iron and steel very much more powerfully than would be possible merely by aid of the lodestone. The process of magnetizing by rubbing is however still frequently employed as a convenient method of making small magnets, as a piece of steel or iron may be magnetized by rubbing it with any other magnet, whether this be a lodestone or an artificial magnet. By the aid of a moderately strong magnet and a few steel sewing needles, it is easy to make a series of experiments on the principal properties of magnets.

There are several ways in which a needle may be rubbed with a magnet in order to magnetize it, the simplest of these being to stroke the needle always in the same direction from end to end with the same end of a steel magnet made in the shape of a straight or bent bar. If two needles are magnetized in this way and hung up by threads, so that they can move freely, or if they are fixed in small slips of cork, and allowed to float on the surface of water, it will be found that the needles will turn, so that two definite ends are juxtaposed, after which they will approach each other until they come into contact. If both the needles are reversed, so that the opposite ends of each are brought together, they will

esis to that of an established fact. I must first premise that a substance which is capable of experiencing any force in virtue of the magnetism of neighboring bodies is called a magnetic substance. Iron is beyond all comparison the most powerful magnetic substance. After iron, and a very long way after it, come the minerals nickel and cobalt; and the sensitive magnetic instruments which are now in the hands of investigators indicate that it is almost impossible to find any substance which is not more or less magnetic—that is to say, which is not more or less susceptible to magnetic action.

Weber supposes that every one of the molecules of which a magnetic substance is built up is itself a magnet; but that the axes of these small magnets are turned in every possible direction. The magnetic actions of the molecules will then neutralize one another, so that the body will not act as a magnet; but if either pole of a magnet be brought near to it, this pole will attract the unlike poles of the molecules, and will repel the like poles, so that the molecules will tend to arrange themselves with their north poles pointing one way and their south poles pointing the other way. The molecules will then act together, and will form a magnet with the portion nearest to the pole of the inducing magnet of unlike polarity to it. It will be of interest to consider one or two experiments which help to establish the truth of this theory.

Take an iron or steel bar—such, for example, as a poker—and hold it parallel to the direction assumed by a freely suspended magnetic needle; we should expect, if the poker were built up of magnetic molecules, that each molecule would try to set itself in a direction parallel to that of the suspended needle, for we should expect the earth to act upon

each molecule in exactly the same way in which it acts upon a suspended magnet. The direction assumed by a freely suspended magnet in this part of the world is not very far removed from the vertical, so we should expect to obtain a fairly good result by simply holding the poker in a vertical position. Now, if the poker is merely held for a few moments, either parallel to the suspended magnetic needle, or simply vertical, and then tested for magnetism by trying whether either end of it has the power of repelling either end of a suspended magnet, it will be found, provided the poker was not magnetized previous to the experiment, that it will not have acquired any sensible magnetic properties. Steel railings, however, which have remained for many years in a vertical position have frequently been observed to have acquired magnetic properties, the lower end having become a north pole, as we should expect, if Weber's theory is true. Now, it must be remembered that all the molecules of the poker are closely packed together, and it is therefore quite possible that the earth may exert a force tending to set them in a definite direction, but that this force may not be strong enough to overcome the cohesion of the molecules. This suggests that we should try by some means to diminish the cohesion of the molecules, and see if any better results are obtained. One way of doing this would be to strike the poker with a hammer, and it will be found that if the poker is held vertical and struck with a hammer, it will become a magnet, the lower extremity becoming a north pole; and if the position of the poker is reversed, and it is again struck, its magnetism will be immediately reversed. Another way of diminishing the cohesion would be to make the poker red hot; and it will be found that if the poker is heated to redness, and then left in a vertical position until it becomes

cool, it will have become a magnet, having its lower extremity a north pole.

It has been observed, moreover, that if a body is magnetized it usually becomes either slightly longer and thinner, or broader and thicker; the nature of the change depending partly on the shape of the body and partly upon the state of strain in which it happens to be at the time of the experiment. Another fact strongly in support of Weber's theory is that when a piece of iron is suddenly magnetized or demagnetized by means of an electric current, a slight sound is heard, which, according to this theory, is due to the sudden turning of the molecules. This production of sound during magnetization and demagnetization was utilized in the construction of one of the earlier forms of telephone receivers, which will be described in a later chapter.

CHAPTER III

MUTUAL ACTIONS BETWEEN MAGNETS AND CONDUCTORS TRAVERSED BY ELECTRIC CURRENTS

AT THE beginning of the present century the Swedish philosopher Oersted observed that when a wire carrying an electric current was held over and parallel to a compass needle, the needle was deflected to the right or left, the direction of deflection depending on that of the current. When the wire was placed underneath the needle, and parallel to it, while the direction of the current remained the same, the direction of deflection was also reversed. The subject was shortly afterward taken up by the great mathematician and physicist, Ampère, who found that the direction of deflection was such that to a person lying along the wire with the current going from his feet to his head, the north pole of the needle would always turn to his left hand. Ampère also discovered that two conductors carrying electric currents attract or repel each other, and otherwise behave just like magnets. These discoveries are of the greatest importance, as they give us the means of detecting the existence of electrical currents, and of measuring their strength by means of magnetic instruments. I will therefore consider them further.

Suppose that a wire has been bent into the form of a circular ring, leaving its two ends free. Let the two ends be connected with the poles of a battery, and the ring sus-

pended from a support in such a manner that the whole circle can turn freely in any direction. It will then be found that the circle will place itself with its plane perpendicular to the direction of the magnetic dipping needle, as a freely suspended magnet is usually called. If the direction of the current through the circuit is reversed, the circle will again take up a position with its plane perpendicular to the direction of the magnetic dipping needle, but its aspect will be reversed—the face that before pointed toward the north now pointing toward the south. If the direction of the current round the circle in each case is noted, it will be found that, looking at the circle from the south side, the current will flow round it in the direction of the hands of a watch; or, as we say, the direction of flow round the circle is clockwise. The face of the circuit which points northward may be called its north pole, and the face which points southward may be called its south pole. *If two such suspended circuits are brought close together, they will be* found to attract when opposite poles are presented to each other, and to repel when similar poles are presented. Thus, when the two circles are parallel to each other they will attract, when the direction in which the current flows is the same in both, and they will repel, when the currents flow in opposite directions round them. It is found generally that conductors carrying parallel currents in the same direction attract each other, and that conductors carrying currents flowing in opposite directions repel each other. Instead of merely a single circle a coil of any form may be used. A coil of considerable length and of comparatively small section is a very suitable form. Such a coil is called a solenoid.

A number of experiments of this nature suggested to Ampère that the properties of magnets might be accounted

for by assuming that every molecule of a magnetic substance had an electric current circulating round it. When a body was magnetized he supposed that all these currents were brought into parallelism. In this case the currents flowing in opposite directions round the adjacent portions of two molecules would destroy each other, and a magnetized rod might therefore be considered as equivalent to a series of currents flowing in the same direction round its circumference; in other words, it would be exactly like a solenoid. Ampère's theory of magnetism is now generally accepted as being most probably true. It is an explanation of magnetic in terms of electrical action, and though it only explains one unknown thing in terms of another, it has the advantage of leaving us to deal with one unknown quantity instead of with two. The principal difficulty in Ampère's theory of magnetism lies in the fact that every conductor such as we are acquainted with is heated when traversed by an electric current, whereas Ampère's molecular currents must flow round the molecules without causing any development of heat, otherwise a magnetic substance would afford a continuous supply of heat, which of course would be in total opposition to experience. So little, however, is known about the manner in which this heating effect is produced, owing to our total ignorance of the internal structure of molecules, that there is really no reasonable ground for assuming that the effects produced in the two cases would be similar in their character.

The discovery of the effect of an electric current upon a suspended magnetic needle gave a simple means of detecting electric currents of moderate strength, and it was very soon found that by making a current flow many times round the needle, instead of simply passing over or under it, the effect

could be greatly increased. In this way it became possible to construct instruments capable of measuring extremely feeble currents. Such an instrument is known as a galvanometer. If a steel bar is placed within a coil of wire traversed by an electric current—that is to say, a solenoid—the bar on being removed from the solenoid will be found to be magnetized. If a current goes round the solenoid in the direction of the hands of a watch with its face directed toward the end from which the current flows, the end of the steel bar within the end of the solenoid at which the current leaves will be found to be a north pole and the other end a south pole. This is easily explained on Weber's theory, for if each molecule of which the magnetic substance is built up is turned with its magnetic axis in the direction indicated by Ampère's rule, previously quoted, it will follow that when a current flows over, and at right angles to, a bar of steel the bar will be magnetized in such a manner that a person lying along the wire, with the current coming in at his heels and going out at his head, and looking toward the bar, will see the north pole on his left hand. The reader will easily see that this agrees with the result obtained with the solenoid.

Not very many years after Ampère's discoveries our own great physicist, Michael Faraday, discovered that momentary electric currents were produced in a conductor which was changing its position relatively to a magnet, or to a conductor carrying an electric current. Some of his experiments we must consider in detail, as they have provided a method of producing electric currents of almost any desired strength very much more cheaply than would be possible with any form of voltaic battery. Take some copper wire covered with gutta percha or cotton, or other insulating

substance, wind it into a coil, and connect the ends with the terminals of a galvanometer—that is to say, with the extremities of the wire which is wound round the suspended magnet. Now take a strong bar magnet and push it right through the coil. The galvanometer needle will then suddenly deflect, first in one direction and then in another, showing that during the passage of the first half of the magnet through the coil a current is produced in one direction, while the passage of the other half gives rise to a current in the opposite direction. This shows that the approach, say of the north pole of the magnet to one face of the coil, produces a current in the same direction as its recession from the opposite face, and that the currents produced by the approach or recession of the north and south poles respectively are in opposite directions. Exactly similar effects are produced if a coil carrying an electric current is used in place of the magnet; but this is not all. Faraday found that not only were momentary currents produced in a conductor by the approach or withdrawal of a conductor traversed by a current, but that when the current arises or dies away in a conductor it produces a current of short duration in neighboring conductors. If two wires are placed parallel to each other, and if the ends of one wire are joined so as to make a complete metallic circuit, while an electric current is suddenly started in the other, by connecting its ends with the poles of a battery, a momentary current in the opposite direction will be produced in the first conductor; and when the battery circuit is broken there will be a second momentary current produced in the neighboring conductor in a direction opposite to the previous one. These momentary currents are called induction currents, and the circuit which produces this phenomenon, either by its motion or by a cur-

rent being excited or dying away within it, is called the primary circuit, while that in which the momentary current is produced is called the secondary circuit.

CHAPTER IV

FORCE, WORK, AND POWER

IN order to understand the conditions which determine the relative advantages of different methods of producing and distributing the electric current, a clear idea of the physical quantities, Force, Work, and Power, must first be obtained. Newton defines a force as whatever causes change in the motion of a portion of matter. Thus, when a train is at rest at a station, a certain force has to be applied to set it in motion and to increase its speed; force is also required to stop the train when once it is in motion, as is shown in a very forcible manner if it comes into collision with a stationary or moving body, such as, for example, another train. When once the train has got up its required speed, it would continue to move at that speed if there were no force tending to bring it to rest, and therefore, if this were the case, a train running along a level line would only require an engine to start it, after which it would continue to move without further application of force until means were taken to bring it to rest.

As everybody knows, however, no train will continue to run on indefinitely without assistance from the engine, and therefore there must be some one or more forces acting upon it in such a way as to retard its motion. The chief of these is the friction between the moving parts. It is unfortunately

impossible to obtain any body in nature which is not already acted upon by some force, so that when a certain force is applied to a body, it is impossible to determine its effect directly, because it is mixed up with those of the forces already acting upon the body; and it is only by a careful study of the motion of bodies under various conditions that it becomes possible to distinguish the different forces acting upon them, and to determine which of the effects are due to each force.

It was by continued observations of this kind that Sir Isaac Newton came to the conclusion that if a body could be found which was acted on by no force, it would either remain at rest or continue to move at a uniform rate in a straight line. Newton also found that if a single force acted upon a body at rest, it would cause it to move with a continually increasing velocity in the direction of the force. He found that as long as the force remained the same the increase in the velocity of the body during each second for which the force was applied was the same, and he also found that the force required to increase the velocity of a body by a given amount in a given time was proportional to the quantity of matter contained in the body, or what is known as its mass.

The general idea of force is a familiar one, but these exact statements about it are necessary in order to be able to measure force, and indeed no one can ever be said really to understand the meaning of any quantity unless he is able to measure it—that is to say, to make an exact numerical comparison between different quantities of the same kind. The statements which I have made about the nature of force do give the means of measuring it. For example, suppose that we have a body, the mass of which

is one pound, and suppose that this body can be removed from the action of all forces, such as the attraction of the earth, the resistance of the air, and so on. Apply to this body during the interval of one second a force which will make it move at a rate of one foot in a second. Then we are able to state from what has gone before that to give the same velocity to a mass of two pounds we should have to apply double the force for a second, or the same force for two seconds.

In order to measure any quantity, it must be compared with some other quantity of the same kind. For example, if we say that a certain distance is ten miles, what we mean is that the distance is ten times as great as some other distance with which we are acquainted and which we call a mile. The mile is said to be the unit, in terms of which the distance is measured; and if the distance is to be measured in miles it will be completely determined by a mere number, such as ten or fifty. It is clear then that the expression of any physical quantity must contain a unit, consisting of a certain quantity of the same kind previously decided on, and a number expressing how many times the unit is contained in the quantity. Now, apply this to the measurement of force.

The unit of force in use for ordinary engineering purposes is the weight of a pound—that is to say, the force with which the earth draws a mass of one pound. The principal objection to this unit is that the pull exerted by the earth upon any mass varies slightly from place to place on the earth's surface, being greatest at the North and South Poles, and least at the Equator; so that where great exactness is required, the place of observation must be stated. This unit has therefore not been adopted for electrical measurements,

nor has any other unit founded upon the English measures of mass and length. For scientific purposes the French metrical system is now universally adopted, and, the system of electrical measurement being a comparatively recent development, the importance of having our electrical measurements given in terms of the same unit as employed in other countries has decided British electrical engineers to adopt units founded on the metrical system.

According to this system, the unit of force, which is called the dyne, is defined as the force which, when applied for one second to a mass of one gramme, will give it a velocity of one centimetre per second. This is what is called an absolute unit—that is to say, it does not vary with the place or time of observation, but depends only on the three fundamental units—namely, the second, which is in use all over the world, and the centimetre and gramme, which are determined by comparison with the standard metre and the standard kilogramme which are kept in Paris.

The next step is to obtain an exact idea of what is meant by a quantity of work. If a body moves under the action of a force, work is said to be done by the body, and the amount of work done is measured by the product of the force into the distance through which the body moves in the direction of the force. If a body is moved against any force, work is said to be done on the body, and its amount is measured by the product of the force into the distance moved in a direction opposite to that of the force. For ordinary engineering purposes, where the pound weight is taken as the unit of force, the unit of work is defined as the amount of work required to lift a mass of a pound to a height of a foot, and is called a foot-pound. The foot-pound being expressed as the product of a pound weight into a length of a foot,

must, of course, like the pound weight, vary from place to place on the earth's surface. The absolute unit of work employed for electrical measurement, and for all scientific purposes, is the work done by a force of one dyne acting in its own direction through a distance of one centimetre. This unit of work is called an Erg.

When work is done upon a body it is found that the body is afterward capable of doing exactly the same amount of work that has been done upon it, and it is therefore said to have energy stored up in it, energy being defined as capacity for doing work. Thus, if a cannon-ball weighing a thousand pounds were lifted to the height of one hundred feet, a hundred thousand foot-pounds of work would have to be done upon it. If the body were then allowed to drive a machine during its fall, it would do exactly the same amount of work by the time it had returned to its original level.

It used to be thought that in a process of this kind some of the work was lost; in other words, that the ball in descending would not do as much work as was required to lift it, for it could not, by any arrangement, be made to lift another ball, of equal weight, to the same height. The reason of this is, that some of the work is always wasted in some such way as overcoming friction, or the resistance of the air. In either case a certain amount of heat is generated, and it has been shown that to a certain quantity of heat, generated by means of friction or other mechanical means, there always corresponds a perfectly definite expenditure of work, so that heat is simply another form of energy. Just as mechanical work can be transformed into heat, so heat can be transformed into mechanical work, but there is this important difference between the two cases: there is

no practical difficulty in entirely transforming a certain amount of energy in the form of mechanical work into heat, but it is impossible, by any means at our disposal, to transform the whole of a given quantity of heat back into mechanical energy.

These considerations give us a glimpse of two principles of the greatest importance in the study of natural phenomena. The first of these is called the "Conservation of Energy," and it asserts that, as the result of far-reaching experience, it is found that whenever energy disappears in one form it reappears without loss in another. This important principle was first stated in definite terms by Professor von Helmholtz some forty years ago, and has been fully confirmed by all subsequent experience, so that it now ranks as one of the most firmly established facts of nature. This is not the place for a detailed discussion of the conservation of energy, but it will be of interest to point out in passing that the principal source from which the energy necessary for the existence of our world is derived is the sun. The heat of the sun's rays evaporates the water of the ocean, and the moisture thus carried up into the atmosphere becomes condensed and falls again in the form of rain, and so feeds the rivers—which may be utilized to drive machinery by means of water-wheels—as they flow back to the sea. The sun's rays, again, build up the mineral constituents of the earth's surface into the various forms of animals and plants, so that the forests and the coalfields are simply great storehouses of the energy given out by the sun in past ages, which energy is utilized when the wood or coal is burned; for the process of combustion simply consists in a recombination between the oxygen of the atmosphere and the other elements contained in the wood or coal, which were separated

from the oxygen with which they were before combined, and built up into the trees of the forest, simply by the energy of the sun's rays.

The other principle to which I referred is known as the "Dissipation of Energy." It is found that in every process by which a transformation of energy can be effected there exists a tendency toward an ultimate transformation into heat of low temperature, from which it is impossible, by any known process, to obtain other useful forms of energy. This principle certainly applies to our own experience; but this experience is very much more limited than that from which the law of conservation of energy is deduced, and it may be that there are natural processes, at present unknown, which are capable of transforming this low temperature heat into some of the other known forms of energy. If this is not the case, and the dissipation of energy is really a universal law of the universe, then the time must come when the whole universe will be one vast inert mass of uniform temperature, and therefore without life or any form of motion.

The term "Power" is used by engineers to denote the rate at which work is done. The power of a steam engine is usually expressed in terms of the horse-power as unit, an engine being said to be of one horse-power when it is capable of doing work at such a rate as to be able to lift 33,000 pounds one foot high in one minute. It may be as well here to point out that this is what is called Indicated Horse-power, and is usually denoted by the letters I.H.P. It is determined by means of an instrument called a "Steam Engine Indicator," which draws a curve representing by its area the product of the length of stroke of the piston into the average pressure of the steam upon it—that is to say, the work done at each stroke of the engine—and therefore gives

the rate of doing work when an engine is making a given number of revolutions per minute.

When a steam engine has to drive a number of machines —such, for example, as dynamos for producing the electric current, which are not always all running at the same time— the rate of working of the engine is controlled by means of a governor, which shuts off a portion of the steam when some of the machines are stopped, or, as engineers say, when a portion of the load of the engine is taken off. In this way the engine is made to work exactly at the rate required at any moment. When the current from the dynamos is used directly for producing the light in the lamps, it is of very great importance to maintain the power of the engine constant within very narrow limits, as if this were not done the speed of the dynamos would vary, and this would produce a corresponding variation in the strength of the light—that is to say, it would give rise to flickering. In order to obviate this, very sensitive governors should be used, but even with the most sensitive governors available it would be impossible to maintain the light perfectly steady unless the regulation of the engine were supplemented by some electrical device for directly regulating the current actually given out by the dynamo. I shall have something further to say about these methods of electrical regulation in a later chapter, as the subject is one of very great importance, and the great improvement in the steadiness of the lamps now in use over those of a few years ago is to a large extent due to the adoption of improved methods of electrical regulation.

The unit of power employed for electrical measurements is called the "Watt," after the great engineer of that name. Its value, as defined electrically, will be given in a later chapter, and it will be sufficient for the present to state that

a Watt is the power developed when $44\frac{1}{4}$ foot-pounds of work are done in a minute, so that 746 Watts are equivalent to a horse-power. This relation is not absolutely exact, because the Watt is an absolute unit of power, while the horse-power depends on the weight of the pound, and therefore varies slightly from place to place on the earth's surface; but it is sufficiently exact for all purposes for which power is expressed in terms of horse-power.

A term in frequent use in connection with engines, and which the reader may meet with in accounts of electric installations as descriptive of the engine power employed, is Nominal Horse-power, usually denoted by the letters N.H.P. This is a very indefinite term, as it is a quantity depending on the length of the stroke and the dimensions of the cylinder; and its relation to the indicated horse-power which can be given out by the engine varies very much with the type of engine. In the case of the engines used for electric light purposes, however, the maximum I.H.P. should be in general about three times the N.H.P., so that an engine of 30 horse-power nominal should be capable, when working up to its full capacity, of giving out about 90 horse-power. The reader should be careful to distinguish between work and power, and remember that power is the rate of doing work. Confusion between these terms is often made even by persons who ought to know better, and it is clearly not an unimportant distinction; for to define the capacity of an engine, what we want to know is, how much work it can do in a given time. If it is merely stated that an engine can do so much work, without stating how long it takes to do it, we are given no information whatever as to the capacity of the engine, for an engine employed to drive a small lathe which might be, say, of half horse-power, may,

if kept pretty constantly at work, do a larger amount of work in the course of twenty years than the engines of an Atlantic liner, of perhaps several thousand horse-power, would do in twenty minutes.

CHAPTER V

SOURCES OF ELECTRICITY

AN electric current is a source of energy—that is to say, it is capable of doing work. This is clear from its power of evolving heat, which, as I have pointed out, is a form of energy; and later on it will be shown that electrical energy may be transformed directly into mechanical work. According, therefore, to the principle of conservation of energy, we cannot expect to maintain an electric current without keeping up a constant supply of energy. The simplest way of considering the different sources of electricity will be to divide them first into two main divisions, according to the kind of energy which is employed to maintain the current. These two kinds of energy are—(1) Mechanical Work and (2) Energy of Chemical Action. The principal kinds of apparatus in which the supply of energy is in the form of mechanical work are—(1) frictional machines, (2) influence machines, (3) magneto machines, (4) dynamos. The apparatus coming under the second heading are the different forms of galvanic or voltaic batteries, now more generally known as primary batteries. Heat energy may also be used to maintain an electric current by means of an apparatus called a thermo-electric battery. This source of energy has as yet been very little employed for generating electric currents for practical

purposes, but it is not improbable that, as our knowledge advances, more economical means of generating thermo-electric currents, as they are called, may be discovered, and energy in the form of heat may then be much more extensively employed for maintaining electric currents for commercial purposes. It must be borne in mind that these distinctions between the forms in which energy is supplied to different classes of apparatus is one merely adopted for convenience, and not one resting upon any fundamental principle. It applies, moreover, only to the source from which the energy is derived immediately before supplying it to the apparatus. For example, frictional and influence machines are generally worked by hand. Here the energy is in the form of mechanical work, but this has previously been stored up in the human body in the form of chemical energy, obtained from the food assimilated by the body, and this chemical energy was in its turn obtained, as already explained, from the energy stored up in the sun. Dynamos, again, are usually driven by steam-power, or sometimes, when available, by water-power. In the former case the source of energy is chemical action—namely, the combustion of the coal; in the second, it is mechanical work due to the water seeking its own level under the action of the force of gravity. In each case, as explained in Chapter IV., the energy is ultimately derived from the sun.

Frictional Machines

The frictional machine has already been alluded to in Chapter I. It used to be employed to a considerable extent for producing the electricity required to fire charges of explosives—as, for example, in blasting operations. At present it is being almost entirely displaced by the influence

machine, and I shall therefore not devote space to the description of any of the forms of instruments employed for such practical purposes. The most convenient form of the machine for experimental purposes is what is called the plate electrical machine. It consists of a disk of plate glass mounted upon an axle, about which it can be made to rotate by means of a handle. Rubbers, usually formed of leather or silk, are attached to the framework on which the axle is supported in such a way that they press against opposite sides of the upper and lower edges of the plate respectively. At a distance of 90 degrees from each of these rubbers there is fixed a bent brass rod surrounding, but not touching, the edge of the plate, and furnished on the side presented toward the plate with small projecting spikes. These two bent rods are attached to the ends of a thick brass conductor, supported upon an insulating stand, usually made of glass. This is known as the prime conductor. It need not have any special form, except that every part of it must be rounded, with the exception of that presented toward the glass plate. The reason of this is that it is found experimentally that the electrification of a conductor always distributes itself entirely upon the surface of the conductor, and in such a manner that the accumulation of electricity is always greatest at the most pointed portions, and least at the most rounded portions. Now I have pointed out that the electricity upon any conductor tends to drive away the electricity of another conductor in the neighborhood, and we should therefore naturally expect the electricity of a conductor to behave in exactly the same way toward other electricity in the same conductor. This we find to be the case, so that at every point of a conductor there is a force acting upon the electricity of the conductor, and directed

outward from it, which tends to break down the insulation of the air or other dielectric surrounding the conductor, and to cause the escape of the charge. This force is greatest where the accumulation is greatest—that is to say, at the most pointed portions. It follows, therefore, that all the portions of the conductor should be rounded, except those facing the glass disk, for here we wish to facilitate the flow of electricity between the conductor and the glass.

Before using the machine, a little amalgam of mercury and tin rubbed up with some tallow is smeared over the rubbers, as it is found that this greatly favors the production of electricity. When the handle is turned, and the glass plate revolves, it becomes electrified positively by friction against the rubbers. The rubbers at the same time lose positive electricity, and to supply this, more positive electricity flows up into the rubbers from the earth with which they are in connection, or, as we might of course say, the rubbers acquire negative electricity, from friction with the glass, and this flows away into the earth, for, as I have previously pointed out, all we know is that what is called a flow of electricity is a flow of something which, in its motion, follows the laws of flow of a liquid, but which way it is flowing we do not know As the plate turns round, the positive electricity is brought opposite to the points, being kept from escaping back to the rubbers by means of silk coverings, which extend from the rubbers to the points in the direction in which the plate is turned, and surrounding its edge. The positive electricity on the plate, as the latter passes between the points, drives the positive electricity of the prime conductor to the further portion, and therefore leaves the points and the portion of the conductor in their neighborhood with a deficiency of positive electric-

ity, or, as we may say, electrifies them negatively. There will therefore be a force acting upon the electricity on the points, tending to drive the negative electrification outward from the points toward the glass, or, in other words, tending to draw positive electricity away from the glass plate on to the points of the conductor. The portion of the glass plate opposite the points thus loses the greater portion of its charge. In passing through the second pair of rubbers, it again becomes charged as before, and this charge is delivered up to the second set of points. This process continues until the potential of the conductor is so nearly equal to that of the plate that the force between the two becomes too small to cause any further transfer of electricity. If, however, some outlet is provided for the electricity which accumulates upon the prime conductor, the action may be continued indefinitely, a stream of electricity being kept flowing from the plate through the prime conductor back to the rubber. If the prime conductor is connected directly with the rubber by means of a wire or other conductor, the arrangement may be represented, according to the water analogy which I have previously used, by means of an endless tube, at one point of which a pump is placed, maintaining a continuous circulation of water through the tube. If the prime conductor and the rubber are both connected to the earth, the only difference in the analogy will be that we must cut the tube at a certain point, and connect its two ends with a reservoir of water, when it is clear that the quantity of water drawn in at one end of the tube, in a given interval of time, will be exactly equal to the quantity expelled at the other end.

Influence Machines

The action of the influence machine may be most easily understood by considering it in the following simplified form. Suppose we have two tin cans, which we will call A and B, supported upon insulating stands, and let a small charge of positive electricity be given to the can A. Now, suppose we have a brass ball, which I will call C, insulated by being attached to a handle of glass or ebonite. Let the ball C be held by this insulating handle close to the outside of A without touching it. While in this position let the ball C be connected with the earth by touching it momentarily with the finger. Now remove the ball by its insulating handle, and bring it into contact with the inside of B, near the bottom. The ball C, being almost completely surrounded by the can B, will give up its electrification almost entirely to B, so that B will become negatively electrified, while the ball will become neutral. Now, hold the ball C outside and close to the vessel B, and touch it for a moment as before. It will then become positively charged by the negative charge on B. Touch the inside of A with it, near the bottom, and it will give up its charge almost entirely to A, thus increasing the positive charge of A. This increased charge is then used in the same manner as the original one, to electrify C negatively, and the charge on A being increased, the negative charge on C will be greater than before. This is given up to B just as before, and the increased negative charge of B is then used to develop, by induction, an increased positive charge on C, which is transferred again to A. Continuing this process, the difference of potential between A and B may be increased to such an extent that if they are brought close together a

spark will pass from one to the other. The influence machine simply consists of an arrangement for carrying out a similar series of operations in rapid succession. A revolving carrier, or series of carriers, is used, together with an inductor, or series of inductors, between which and the carrier a certain small difference of potential must be excited in order that the machine may start. The carriers as they pass the inductors are electrified by induction, and when passing out of the sphere of influence of the inductor they are touched by a spring connected with a collector, which in its turn acts as an inductor, and in this way a very small initial difference of potential can be rapidly increased to a considerable extent. With the older forms of influence machines it was necessary to begin by electrifying one of the inductors. Influence machines, however, are now made which are able to excite themselves without external assistance by means of the infinitesimal difference of potential which invariably exists between the inductors, and which is sufficient to begin the series of operations. The reader may be acquainted with Clarke's electric gas-lighter, which consists, to outward appearance, of a flat disk some two or three inches in diameter, from opposite sides of the edge of which project, on one side a handle, and on the other a tube of any desired length, containing a pair of insulated wires, the ends of which come close together without touching, just within the further end of the tube. To light the gas with the instrument the further end of the tube is held in the gas jet, and a small projection in the edge of the disk is pressed smartly down, upon which something is heard to be spinning rapidly inside the disk, and sparks are seen to pass between the two wires just within the end of the tube. This is simply a small influence machine of the kind de-

scribed, the mechanical arrangement being such that on pressing the button on the edge of the disk the revolving portion is set in rapid motion. The Wimshurst machine, so called from the name of its inventor, is another example of influence machines. It consists in its simplest form of a pair of glass disks, mounted upon a common axle, close together, but without touching each other, in such a way that they can be made to revolve rapidly in opposite directions. Strips of tin-foil are pasted radially on the outside surfaces of the glass, and metallic collecting brushes are made to press against the revolving pieces of tin-foil as they pass certain fixed positions. Large machines of this kind are capable of imitating the effects of a thunder-storm upon a small scale, giving sparks several feet in length and following in rapid succession. In a dark room these series of sparks exactly reproduce the appearance of forked-lightning on a small scale. Small influence machines, somewhat similar to those used for gas-lighting, are employed for igniting blasting charges in mines.

Magneto and Dynamo Machines

These machines all depend upon the principle that electric currents are induced in conductors which are moving in the neighborhood of magnets, or more generally, which are moving in a field of magnetic force, which may be due to the presence of either permanent or electro-magnets. Dynamos are now always employed when powerful electric currents are required for commercial purposes, such as for electric lighting or electro-plating. It is necessary, therefore, in order to understand many of the most important applications of electricity to commercial and domestic purposes, to obtain something more than a mere vague, general

idea of the construction and action of a dynamo; and as the subject must be treated in some detail in order to make it intelligible, I shall devote a separate chapter to it. I therefore pass on to the consideration of

Galvanic or Voltaic Batteries

These are used for the purposes of telegraphy and telephony, and for many others in which only comparatively small currents of electricity are required. A galvanic or voltaic cell consists essentially of two different metals immersed in some substance, generally a liquid, composed of two or more chemical elements, one at least of which tends to combine with one or other of the two metals, or with one more than with the other. When the two metals are electrically connected outside the liquid, the circuit is said to be closed; when they are not so connected, the circuit is said to be open. If the connecting wire is cut, its ends are called electrodes, the free end of the wire connected with the plate from which the current is flowing through the connecting wire being called the positive electrode, and the free end of the other wire being called the negative electrode. A very simple form of cell consists of a plate of zinc and a plate of copper partly immersed in sulphuric acid. It will generally be found, even if there is no electrical contact between the zinc and copper, except through the liquid, that the zinc will dissolve slowly in the acid, giving off bubbles of gas at different parts of its surface; but if the zinc and copper are connected by a wire, the action will be found to increase considerably. The oxygen set free by the decomposition of the sulphuric acid is given off at the zinc plate, while the hydrogen is given off at the copper plate. This process is effected in the following manner: Sulphuric acid consists

of two atoms of hydrogen in combination with an atom of sulphur and four atoms of oxygen, and is therefore represented by the formula $H_2 SO_4$. The molecules of acid are continually being broken up, chiefly, there is reason to believe, into the groups H_2, and SO_4. When the electrical potential of the liquid is the same throughout, these groups recombine, as fast as they are broken up, to form fresh molecules of $H_2 SO_4$; but when a difference of potential is maintained between different portions of the liquid, the molecules of hydrogen move from places of higher to places of lower potential, just as if they carried a positive charge of electricity; while the groups of SO_4 travel in the opposite direction, as though their electrification were negative. Thus, though the two constituents continually form fresh molecules during the journey, only to be again broken up, there is, on the whole, a continual flow of hydrogen in one direction, and of SO_4 in the other. The hydrogen is given off at the copper plate; while the SO_4, on arriving at the zinc plate, where there is no free hydrogen to combine with it, takes the hydrogen from a molecule of water (H_2O), and leaves the oxygen free. The chemical action which goes on before the circuit is closed contributes nothing toward the current of electricity, and is known as local action. It is caused chiefly by impurities in the zinc, and may be almost entirely obviated by amalgamating the zinc with mercury.

The manner in which the E.M.F. is produced in a galvanic cell is still an open question among electricians, but the consideration of the following experimental facts will help the reader to attain a general understanding of the action of a cell:

(1) If a piece of copper is placed in contact with a piece of zinc a difference of potential will be produced at the

point of contact, the zinc becoming positively electrified and the copper negatively, so that the potential of the zinc is higher than that of the copper. The charges so produced are always very small.

(2) If either the copper or zinc is immersed alone in the dilute sulphuric acid a difference of potential will be produced between the metal and the liquid; but if the two metals are immersed side by side into the liquid then no electrification can be detected, so that all three must be at the same potential.

(3) If a piece of copper is now joined to the zinc, the copper, being in contact with the zinc, will become negative, and the zinc positive, while the liquid and the copper immersed in it will still have the same potential as the zinc—that is, they will be positive. Now, suppose the piece of copper attached to the zinc to be bent round and connected with the copper plate of the cell, then the action of the liquid is continually to do away with the difference of potential caused by the contact of copper and zinc, and this requires a flow of electricity from zinc to copper within the liquid, and therefore from copper to zinc in the connecting wire.

When a series of galvanic cells is so arranged that the zinc of each cell is connected with the copper of the next cell, the arrangement is called a galvanic battery, or voltaic battery. If each cell is made of similar materials, the difference of potential, or electro-motive force, of the battery will be equal to the product of the electro-motive force of one cell by the number of cells.

If a cell of the simple kind already described is employed, or a battery of such cells, for producing an electric current, after a short time a number of small bubbles of gas will be observed to be adhering to the copper plates within

the liquid, and at the same time it will be found that the E.M.F. of the battery has become very much less than it was at first. It can be shown that this is due to an E.M.F. opposite in direction to that of the battery being set up between the bubbles and the copper.

This phenomenon is known by the name of polarization, and the E.M.F. due to it is called the E.M.F. of polarization. The polarization of a cell may be diminished by any means which will cause the bubbles to rise to the surface instead of remaining adhering to the copper as, for example, by stirring the liquid, or by blowing air through it. If the surface of the copper is roughened the gas will collect chiefly at the projecting portions, and therefore the bubbles will attain a size sufficient to rise to the surface much sooner than if the surface were smooth. With the object of obtaining a rough surface of this kind, Smee devised a cell which differed from the typical form described only in the fact that the plates of copper were replaced by plates of silver covered with a coat of platinum in a very fine state of division. These plates give off the bubbles very freely, but still the remedy is only a partial one, and the E.M.F. of the battery is found to fall considerably after it has been in action for a few minutes.

A much more efficient means of overcoming polarization is to employ, as the liquid surrounding the plate at which hydrogen is set free, a solution containing some highly oxidizing substance. The hydrogen as it is set free will then, instead of forming into bubbles, unite with the oxygen of this substance to form water. These substances, however, cannot be employed in a zinc copper cell, as the copper would be dissolved in them, and some of them would also attack the zinc as soon as the circuit was broken. This

difficulty was overcome by Poggendorff, who devised the "Bichromate" cell, consisting of plates of carbon and zinc immersed in a solution of bichromate of potash, to which a small quantity of sulphuric acid has been added. This solution begins to dissolve the zinc as soon as the circuit is broken, and therefore arrangements have to be made for lifting the zinc out of the solution. Nitric acid is a highly oxidizing substance, and very suitable as a liquid in which to immerse the positive plate; but it will not do to have the zinc immersed in nitric acid, as the action of the acid on the zinc as soon as the circuit is broken would be exceedingly rapid. Bunsen therefore devised a cell, in which the positive plate is formed of carbon immersed in strong nitric acid. The acid is placed in a porous pot, and this porous pot is itself placed in a vessel containing a zinc plate and dilute sulphuric acid. The porous pot allows the liquid to pass into its pores, so that the products of the chemical decomposition going on in the cell can pass through it under the influence of E.M.F.; but if the liquids inside and outside the porous cell respectively are at the same level, ordinary mixture of the liquids will only take place exceedingly slowly. The Bunsen cell is a very good one where a strong current is required, but it is necessary after using it to soak the carbons for some hours in water to get rid of the nitric acid which they have absorbed. In a cell devised by Mr. Justice Grove, and therefore known as the Grove cell, the carbon is replaced by a sheet of platinum, which can be washed much more easily. After using either of these cells the solutions must be poured out, as otherwise gradual mixture of the two will take place. Neither of them is pleasant to use in a room, as they give off an exceedingly pungent gas known as nitrous oxide.

The polarization difficulty has been overcome in another way in the Daniell cell, which consists of a zinc rod or plate immersed in sulphuric acid, and a copper plate immersed in a saturated solution of sulphate of copper. The solutions are separated by a porous division, one of them being usually contained in a porous pot immersed in the other. In this cell the hydrogen, set free as the zinc dissolves in the acid, passes through the porous division into the solution of sulphate of copper, which it decomposes, forming sulphuric acid, and depositing a layer of copper upon the copper plate. The strength of the solution is kept up by placing some crystals of the salt in it, which dissolve as fast as the copper is deposited, so that the solution of sulphate of copper is maintained at the point of saturation.

Another battery which must be mentioned, as it is extensively used for telegraphic and telephonic purposes, and also for ringing electric bells, is the Léclanché cell. This cell consists of a vessel containing a solution of salammoniac, in which are immersed a zinc rod or plate, and a porous pot packed with lumps of carbon and powdered binoxide of manganese. The zinc dissolves in the salammoniac, and bubbles of hydrogen are formed on the carbon plate; so that if the circuit is kept closed for any length of time, the E.M.F. will be found to fall considerably. This affords an explanation of a fact which may probably have been noticed by many of my readers, that an electric bell, worked, as is usually the case, by means of one or more of these cells, will soon cease ringing if the button is kept pressed down, and will sometimes fail to act if it has been rung a good many times in rapid succession. When the battery is left to itself for a short time the oxygen from the oxide of manganese gradually combines with the hydrogen bubbles

to form water, and in this way the E.M.F. of the battery is restored to its original value.

Batteries like the Grove or the Bunsen are very suitable for maintaining an electric light for an hour or two for experimental purposes, and a bichromate battery will do very well for the same purpose if the light is only required for a still shorter time—as, for example, to supply current for a lamp to stand at the bedside to observe the time by the clock during the night—the battery being brought into action when required by pressing down a rod which immerses the zinc in the solution, a spring lifting it again as soon as the pressure is removed. Small incandescent lamps supplied with current from a bichromate cell are often sold as reading lamps, but after burning from half an hour to two or three hours, according to the size of the cell, they will gradually become dim and ultimately cease to glow altogether, when the battery must be refilled with fresh solution. It is impossible commercially to supply the electric light by means of any form of galvanic battery, or primary battery, at present known to us, for the simple reason that in these batteries the energy is obtained from the consumption of zinc or other material, which costs many times more than coal. The object in using a dynamo instead of a battery to supply the current is, that instead of having to burn an expensive fuel, such as zinc, to obtain energy, it can be obtained by burning the cheaper fuel, coal; and though a considerable amount of the energy obtained from the coal is lost, first in the process of transforming heat into mechanical work in the steam engine, and secondly in the transformation of mechanical into electrical energy in the dynamo, still the difference between the cost of coal and that of zinc is so great that the cost of producing electricity on a large

scale by means of a dynamo is many times less than it would be if any form of primary battery were used.

CHAPTER VI

MAGNETIC FIELDS

AS there will be frequent occasion in this and the following chapters to make use of the term "Magnetic Field," it will be important for the reader to obtain an exact conception of its meaning.

A Magnetic Field may be defined as a region within which magnetic force acts—that is to say, it is a region of such a kind that if a magnet is introduced into it, it will be subject to the action of certain forces in virtue of its magnetism; and if a magnetic substance is introduced into such a region it will become magnetized—that is to say, it will acquire magnetic properties. A clearer idea of what is meant by a magnetic field, or a field of magnetic force, will perhaps be obtained by supplementing this definition by the consideration of some field of force of a more familiar character than magnetic force. Consider, for example, what happens when a comet is moving through space in the neighborhood of the solar system.

The comet would be attracted by the sun, and if it were originally at rest, and the sun were the only other body in the universe, the comet would be drawn directly toward it, and the force tending to draw the two bodies together would increase, as they approached each other, at such a rate that when the distance between the sun and the comet was halved the force would amount to four times its original

value; when the distance was diminished to one-third of its original amount, the force of attraction would be nine times as great as at first; when the distance was diminished to one-fourth, the attraction would be sixteen times as great, and so on. In other words, the attraction between the two bodies would be inversely proportional to the square of the distance between them. Considering then merely the motion of the comet in obedience to the force acting upon it, it may be regarded as moving in a field of force of such a character that the intensity of the force is the same at all points of any spherical surface described with the centre of the sun as its centre, while the direction of the force is always along the radius. This field of force may be mapped out in such a way as to exhibit at a glance the magnitude and direction of the force exerted upon the comet at any point.

Describe a number of spherical surfaces, each having the sun as centre, and therefore lying one within the other, and let the distance between any sphere and the one immediately outside it be calculated from the law of attraction in such a way that the force always diminishes by the same amount in passing from any one sphere to the next outside it.

If these spheres are drawn close enough, the whole region will then be mapped out in such a way that the ratio of the rate of change of the force acting on the comet at any point of its path, to that at any other point, will be the same as the ratio of the distance between the two adjacent spheres inclosing the first point, to the distance between the two adjacent spheres which inclose the second point.

The direction of the force at any point will be along the line joining that point to the common centre of the spheres, that is to the centre of the sun, and it will therefore always

be perpendicular to the surface of the sphere passing through the point. Such a line, which represents the direction of the force acting on the comet at any point, is called a line of force; and each sphere, being a surface everywhere perpendicular to the direction of the force, is called a level surface.

It is clear that in the present case the distance between two adjacent spherical surfaces, at such a small distance apart relatively to their distance from the common centre that the difference between these distances may be neglected, will be inversely proportional to their common distance from the centre of the field of force. The field will therefore be completely defined by the statements—

(1) That the level surfaces are spheres with the centre of the sun as their common centre.

(2) That the distance between any two adjacent spheres is inversely proportional to the distance of their surfaces from the centre.

It will be convenient, for the purpose of applying these considerations to magnetic fields, to define the fields by means of what are called unit tubes of force instead of by the level surfaces.

Imagine a small closed curve to be drawn on one of the spheres, and let the force across the small area inclosed by the curve be taken as the unit of force, then all the lines of force passing through the boundary of this small area will form a tube, which is called a unit tube of force. In the case of the field of gravitation force due to the sun, these tubes will clearly be cones having their vertices at the centre of the sun, and it could easily be shown mathematically that the force of attraction on a unit mass placed anywhere in the field of force would be inversely proportional to the

area of the section of the tube made by the level surface through the point.

Any portion of the field of force will thus be fully defined by the unit tubes of force drawn in this manner, for the direction of the line of force at any point gives the direction of the force, while the number of unit tubes passing through unit area on the level surface through the point may be taken as a measure of the intensity of the force. So far the comet has been supposed to be acted on only by the force of attraction of the sun. This, however, is not really the case, for every planet and satellite of the solar system is at the same time attracting the comet toward itself with a force proportional to its mass, and inversely proportional to the square of its distance from the comet.

Now, according to the experimentally observed laws of motion discovered and enunciated by Sir Isaac Newton, the force exerted by each body is independent of the forces exerted by the others, and therefore it becomes a mere question of mathematical calculation to map out the field of force in which the comet is actually moving.

Such a field may, as before, be defined by means of its level surfaces, or by means of its unit tubes of force; but the level surfaces will no longer be spheres, and the lines of force will no longer be straight lines. Now, just as the field of force in which the comet is moving has been mapped out, so we may map out a field of magnetic force; and it was first in connection with the mapping out of magnetic fields that Faraday introduced the idea of lines of force, and the method of mapping out a field of force by their means. It seemed, however, to me that it would be easier to approach the subject through the better known case of gravitation force.

A very simple means of studying magnetic fields experimentally is to place a sheet of stiff paper or cardboard in the portion of the field in which we wish to know the distribution of magnetic force, and to dust it over with iron filings, when the filings will arrange themselves along the lines of force. It will be of interest to illustrate this by considering a few simple cases.

Let the magnetic field be that due to a single magnetic

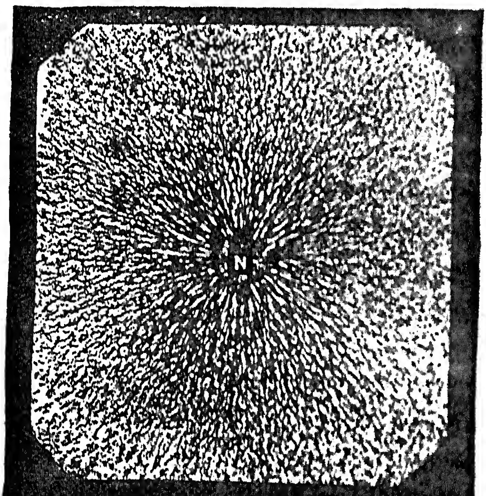


FIG. 1.

pole. This may be practically obtained by holding a long narrow bar magnet vertically under the cardboard, with one end in contact with its under surface, and then dusting the filings upon the upper surface, tapping the card slightly during the process. The further pole of the magnet will be so far from the card that it will not produce any sensible effect, so that the field will be practically that due to the nearest pole.

The filings will then arrange themselves in a series of lines radiating from a common centre immediately over the pole of the magnet in contact with the cardboard, as shown in Fig. 1. In this way, of course, we only obtain a representation of a section of the field of force. If we could obtain a single separate magnetic pole—which, as a matter of fact, is impossible—the magnetic field surrounding it

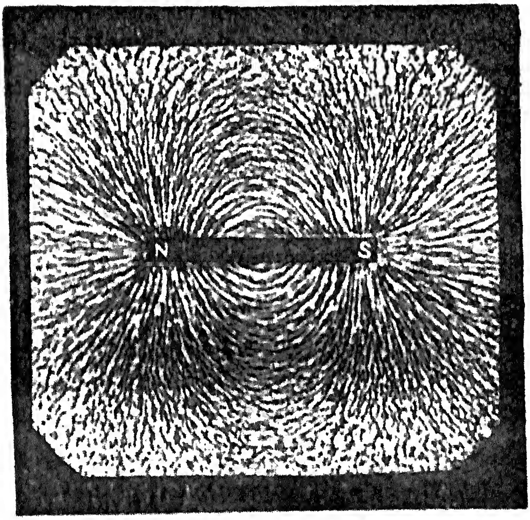


FIG. 2.

would be of a character exactly similar to the field of force surrounding a sphere of gravitating matter, as in the case of the sun previously considered.

If the bar magnet is held horizontally under the cardboard so as to touch along its whole length, the filings will arrange themselves as shown in Fig 2, which there represents a section, through the line joining the poles, of the field of force due to a pair of opposite poles.

The actual form of the lines of force in the space surrounding the poles of a magnetized bar is shown in Fig. 3.

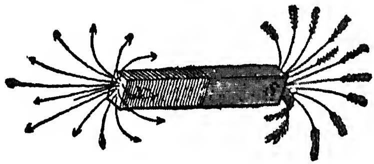


FIG. 3.

The field of force surrounding an electric current may be exhibited in a similar manner. Thus bore a hole through a piece of cardboard and pass a wire which carries a current up through the hole, allowing it to stand at right angles to the card. The iron filings will then arrange themselves in a series of circles, having this hole as their common centre, as shown in Fig. 4. The level

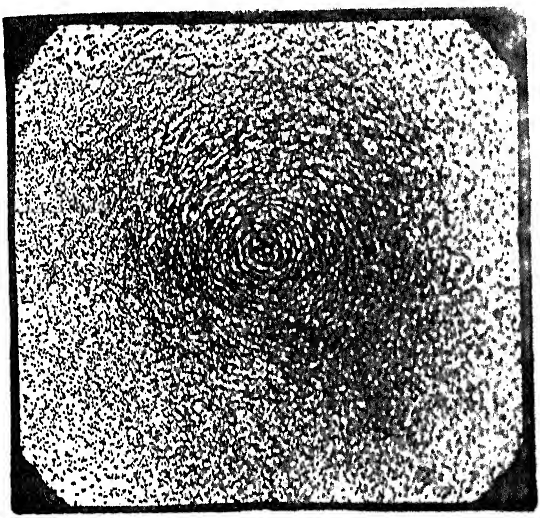


FIG. 4.

surfaces, being perpendicular to the lines of force, evidently consist, in this case, of a series of planes passing through the straight wire.

In the case of the field of gravitation force in which

a comet was moving, considered at the beginning of the chapter, the direction of the force at any point would be that in which the comet would move if it were placed at that point without any motion being given to it other than that due to the gravitation force.

In the case of a magnetic field, a north pole and a south pole tend to move in opposite directions along a line of force, and we select as the positive direction of a line of force, or the direction of the magnetic force at a point, that direction in which a north pole would move if unconstrained. The reason that the iron filings arrange themselves along the lines of force is that they become magnetized with their axes in the direction of their greatest length, and equal and opposite forces acting upon their opposite poles set them along the lines of force; just as when two strings are tied to the end of a stick and pulled in opposite directions the stick will set itself in a straight line with the pair of strings.

It is evident, from inspection of Fig. 4, that if one of the poles of the magnet could be separated from the other, it might be made to rotate continuously round a wire carrying an electric current; and though it is impossible to do this, the truth of the statement can, notwithstanding, be demonstrated in several ways.

Perhaps the simplest of these is to place a magnet, formed out of a long, thin, flexible steel wire, parallel and close to a wire carrying a current, when it will be found that the two poles will rotate round the wire in opposite directions, twisting the magnet round the wire.

It is clear, then, that an electric current is surrounded by a series of what may be called "magnetic whirls," and therefore it becomes easier to see the possibility of an electric current being set up in a wire moved across the lines of

force of a magnetic field, as Faraday found to be the case. For both magnets and conductors carrying currents give rise to actions going on in the medium surrounding them of such a kind as might be imagined to arise from a rotation of portions of the medium; and therefore when a wire is moved across the lines of force magnetic whirls are set up round the wire, involving the existence of what is called a current of electricity.

Faraday found that the E.M.F. excited in a conductor by moving it across the lines of force was in the direction at right angles to that of the motion and to the direction of the lines of force, and the direction of its action was given by the rule that if we suppose a man swimming in the conductor to turn so as to look along the line of force in the positive direction, while the conductor moves toward his right hand, he will be swimming with the current induced by the motion. The amount of the E.M.F. Faraday found to be proportional to the number of unit tubes of force cut per second, and therefore proportional to the intensity of the field and to the length and velocity of the conductor.

From what has just been stated as to the direction of the E.M.F. excited in a conductor when it moves across the lines of force, it follows that if a closed circuit, such as a circle of wire, be moved across them, the passage of a unit tube of force from the inside to the outside of the area inclosed by the circuit will produce an E M F. equal and opposite to that due to the passage of a unit tube from the outside to the inside. The current round the circle will therefore be proportional to the rate of increase or decrease in the number of unit tubes enveloped by the circuit.

Instead of moving a conducting circuit in a magnetic field

in such a manner as to vary the number of tubes of force enveloped by it, this variation may be effected by varying the magnetic field while the conductor remains stationary. Thus if a magnetic field is made to grow around a straight wire forming a portion of a conducting circuit, by starting a current in a second circuit, part of which is parallel and close to the straight wire, it will give rise to an induced current in the latter in the opposite direction to that of the inducing current, and continuing as long as the inducing current continues to increase—that is to say, as long as the magnetic field continues to grow. When the inducing current assumes a steady value the variation in the magnetic field, and therefore also the induced current, will cease. If the inducing current is now allowed to die away the magnetic field will also begin to die away, giving rise to an induced current in the straight wire in an opposite direction to that of the former one, and lasting until the inducing current has completely ceased.

If a current is suddenly started in a straight wire a magnetic field will be made to grow round it, and will give rise to an E.M.F. opposed to that of the inducing current, the effect of which is to retard the increase of the primary current. If the primary current is allowed to die away, the resulting variation in the magnetic field will give rise to an E.M.F. in the direction of the primary current, the effect of which will be to make the current die away more slowly than it otherwise would. This phenomenon is known as self-induction. It is easy to see that the self induction of a straight wire of given dimensions would be greatly increased if it were wound into a coil, as this would bring the different parts of the circuit much closer together, and would therefore greatly increase the mutual induction of the

different portions—that is to say, it would increase the self-induction of the circuit.

It is possible to arrange a series of magnets in such a manner as to make a magnetic field within a certain portion of which the magnetic force is everywhere equal and in the same direction. When this is the case the magnetic field is said to be uniform, and the lines of force are all parallel, and the section of a unit tube by a level surface is the same at every point. If any closed circuit is moved parallel to itself across the field, the number of unit tubes enveloped by the circuit will therefore remain unchanged, so that no current will be produced; but if the circuit is made to rotate, the number of unit tubes enveloped will vary, and therefore currents will be induced in it during the motion.

Suppose, to take as simple a case as possible, that the circuit consists simply of a circle of wire. In order to fix the ideas, suppose that the lines of force are horizontal, and that the positive direction—that is to say, the direction of the magnetic force—is from left to right. Let the circle be capable of rotation about a horizontal axis passing through its centre, and perpendicular to the lines of force. Let the circle be made to turn about this axis in the direction of the hands of a watch, and consider what happens, starting with the circle in a horizontal position. In order to define the direction of the current round the circle, suppose a watch to be placed in it with its face in its plane, and directed toward the observer in the initial position. Applying Faraday's rule, it is then easily seen that during the first and last quarter revolutions the current round the circle will be in the opposite direction to the motion of the hands of the watch, and in the same direction as that of the hands during the second and third quarter revolu-

tions. The reversal of the current will therefore take place each time that the plane of the circle passes through the position of parallelism with the lines of force.

If, then, the circle is made to spin about a horizontal axis, it will be traversed by a series of currents alternately in opposite directions, the change in direction taking place at each half revolution.

An approximately uniform field may be produced between the poles of a magnet having its ends hollowed out to a suitable shape, and bent round so as to bring them close together.

A conductor such as has been described, but having its ends cut at a point on the axis of rotation, and connected with conducting wires to carry the currents produced wherever they are wanted, and arranged in such a manner as to be capable of rotating between the poles of a magnet, is nothing more nor less than a dynamo in its simplest ideal form.

For some purposes—as, for example, for producing the electric light—the currents may either flow alternately in opposite directions or continuously in the same direction. For other purposes, however—such, for example, as electroplating—it is necessary to have the current always in the same direction through the conducting wires or leads, as they are often called, and in that case it is necessary to make use of some kind of arrangement which reverses the connections between the rotating conductor and the leads whenever the direction of the current in the rotating portion is reversed—that is to say, at every half revolution. An arrangement of this kind is called a commutator.

Professor Sylvanus P. Thompson, in his work on "Dynamo-Electric Machinery," from which, by the kind per-

mission of the author and publisher, the illustrations in this and the following chapter have been taken, sums up the guiding principles which have to be borne in mind in constructing a dynamo, as follows—(1) The field magnets should be as strong as possible, and their poles as near to the armature as possible; (2) the armature should have the greatest possible length of wire upon its coils; (3) the wires of the armature coils should be as thick as possible, so as to offer little resistance to the induced currents; (4) the speed of rotation should be as great as possible.

These are by no means the only conditions which have to be considered in designing a satisfactory dynamo; but even when nothing further is taken into account, a system of give and take has to be adopted, as it is impossible to carry out each of these conditions to the fullest possible extent in the same machine, and therefore it is necessary to effect such a compromise as will give the best result for the purpose in view.

CHAPTER VII

ELECTRICAL MEASUREMENT

SO LONG as electricity remained merely a laboratory science very little attention was paid to electrical measurement, outside the small circle of great mathematical electricians who were engaged in studying electrical phenomena, and investigating the general laws to which they were subject, from a purely scientific point of view.

For a long time after electricity had become more or less a subject of general interest, the attention of by far the greater number, even of those who were engaged in teaching the subject, was mainly confined to the description of phenomena without regard to their quantitative relations. Text-books of not many years ago scarcely even touched upon these quantitative relations, although the fundamental principles of electrical measurement had been fully worked out by Gauss, Weber, Sir William Thomson, and a few others.

It was the application of electricity to practical purposes which changed all this; and especially the rapid and comparatively recent development of electric lighting, and of the application of electricity to the distribution of power.

An electrical engineer requires to know not only whether a current will be produced under certain circumstances, but also the exact effect of each one of these circumstances, so that he may be able to determine the conditions most favor-

able to its economical production, and design his apparatus and system of distribution accordingly.

It is not sufficient for him to know that a smaller proportion of energy is wasted in the form of heat when the current is carried by a copper conductor than if an iron conductor of the same dimensions were employed. He wants to know exactly how much one is better than the other, so that he may be able to decide whether it is more advantageous to incur the increased expense of copper conductors in order to save the waste of energy, or whether the increase in cost would more than counterbalance the saving effected in the motive-power.

If the balance of advantage is in favor of copper—as it invariably is, for example, in the case of the conductors which carry the currents for electric lighting—he has to determine the most economical dimensions of the conductors to be employed in carrying the current required.

This is a problem which has to be determined almost daily in the case of laying down electric light cables, which are now spreading so rapidly even in London. These requirements of the practical engineer, which began to make themselves sensibly felt when submarine telegraphy first became a realized fact, afforded a most powerful stimulus to the development both of a system of electrical measurement and of the means for practically carrying it out.

If the development of the system itself had been entirely in the hands of the mathematical electricians, and had been uninfluenced by practical considerations, it would have developed much more slowly; and would probably, to some extent at any rate, have failed to fulfil the requirements of the practical engineer.

If, on the other hand, it had been developed by men

acquainted only with the practical side of the question, unaided by scientific theory, it would never have been so simple and convenient, even for practical purposes, as that now in use. It would, in fact, have borne the same relation to the actually existing system that our English system of Weights and Measures does to that which was developed by scientific men in France, which, in addition to being one of the greatest boons to the population of the country in which it took its rise, has been found so greatly superior to any system developed without the aid of scientific knowledge that it has been universally adopted for the purpose of scientific measurements, and has been made the basis of the practical system of electrical measurement.

The British Association Committee, with Sir William Thomson as its guiding spirit, played the most important part in the development of this system, which is now in use by electrical engineers of every nationality, and in every part of the world where electricity is employed for practical purposes.

The foundation of the science of electrical measurement was really laid by the investigations of Cavendish about the middle of the last century, in which he showed that the observed fact that a hollow electrical globe does not communicate any portion of its charge to a small globe in communication with and inclosed within it, leads by strict mathematical reasoning to the conclusion that the attraction between two small electrically-charged bodies is inversely proportional to the square of the distance between them. Until Professor Clark-Maxwell in 1879 edited Cavendish's unpublished papers the French physicist Coulomb had generally been credited with this discovery, as Cavendish, though he communicated some of his preliminary results

to the Royal Society in 1771, never published his definite proof of the law.

Cavendish's prior discovery does not in any way detract from the merit of Coulomb, who in the year 1875 communicated to the French Academy the description of a series of experiments with his torsion balance, in which he had directly demonstrated the law of inverse squares both for electrical action and for the attraction and repulsion between magnetic poles. The discoveries of Cavendish and Coulomb laid the foundation of the theory of electrostatics and of magnetism respectively; and Oersted's discovery in 1820 of the mutual actions between electric currents and magnets formed the basis on which Ampère built up his mathematical theory of electro-magnetism.

It has been pointed out in Chapter III. that these investigations gave the means of measuring electric currents by their actions on magnets and upon each other; and, indeed, Ampère was the originator both of the idea and of the name of the Galvanometer.

In the same year in which Ampère described this instrument Schweigger modified Ampère's original idea by winding a wire into a coil, in the centre of which a magnetic needle was suspended, and indicated by its deflections the direction and strength of the current traversing the coil.

In the year 1837 Pouillet modified this instrument so as to make it capable of exactly comparing the strengths of two currents by means of the respective deflections of the needles, instead of the deflection only giving a general idea of the current strength. The "Sine" and "Tangent" galvanometers, invented by him, are still among the instruments in most frequent use for laboratory measurements of electric currents.

In the year 1846 Ampère's investigations on the mutual actions of conductors carrying electric currents led Weber to the invention of the electro-dynamometer, an instrument in which an electric current traverses in succession a fixed coil and a small movable one suspended within it, and the strength of the current is determined by means of the deflection of the smaller coil.

While advances were thus being made in the construction of instruments for use in electrical measurement, the theory of the subject was by no means standing still.

In the year 1827 Ohm published a most important paper, in which he showed that the strength of the current between any two points of a conductor is proportional to the electromotive force between the two points, divided by a certain quantity depending only upon the dimensions and material of the conductor, which he called its "electrical resistance."

For some years after this, electricians continued to follow Ohm's example in expressing the resistances of different portions of a circuit in terms of the resistance of a selected portion of it.

In the year 1837, however, Pouillet took the very important step of expressing all his measurements of resistance in terms of the resistance of distilled mercury, using as a standard the resistance of a column of mercury of a measured length, contained in a glass tube, terminating in wide cups in order to allow of the necessary connections being made.

In the year 1833 Gauss published a most important paper, in which he described the theory and method of measuring the intensity of terrestrial magnetism and the strength of a magnetic pole in absolute measure—that is to say, in terms of units depending only on the units of space, time, and mass which were chosen. Those adopted

by him were the millimetre, the second, and the milligramme.

In 1851 and subsequent years Weber, who had been associated with Gauss in his magnetic measurements, developed a definite system of electrical measurement expressed in terms of absolute units, and founded upon Gauss's absolute system of magnetic measurement. In a paper published by him in 1851 he pointed out that, according to Ohm's law, the resistance of a closed circuit is determined in terms of the E.M.F. and the current strength, and he proceeded to define the unit of resistance as the resistance of a closed circuit, in which unit E.M.F. produces a current of unit strength.

He then went on to show that E.M.F. and current strength require for their expression in absolute measure only the determination of the strength of a magnetic pole, and of the intensity of terrestrial magnetism, both of which Gauss had shown how to determine.

The advantages of Weber's system were at once recognized by Sir W. Thomson, and in the year 1861 a Committee of the British Association was appointed, at his suggestion, for the consideration of standards of electrical resistance, and the plan of work was subsequently extended so as to include the general question of electrical measurement. The committee thus formed requested the co-operation of the principal British and foreign electricians, including both purely scientific men and practical engineers; and the final conclusion at which they arrived was to adopt a series of practical units obtained by taking convenient multiples of the absolute units. The principal units required by practical engineers are those of quantity, of current, of resistance, and of potential or E.M.F.

Now, Ohm's law gives a relation between the last three of these, and the first two are very simply related; so it is sufficient to determine any two of them. It will greatly assist the reader in forming a conception of the quantitative relations which have to be considered by electrical engineers to understand clearly how these units are obtained, and I shall therefore indicate very briefly the simple course of reasoning by which the units of current and resistance are expressed in terms of absolute units.

Coulomb's experiments had shown that the force acting between two magnetic poles is proportional to the product of their strengths divided by the square of the distance between them; and therefore, unless a useless factor is introduced, the force may be defined as equal to this expression; from which it will follow that the unit pole, or pole of unit strength, will be that which repels a similar pole at a distance of one centimetre, with a force of one dyne.

Now, the force exerted on a unit magnetic pole by a current whose distance from it is constant—that is to say, by a current flowing in a conductor in the form of a circular arc described with the pole as centre—is found to be proportional to the length of the arc divided by the square of the radius of the circle, and therefore the force on a magnetic pole may be defined as being equal to the product of the length of the arc, the current through it, and the strength of the pole, divided by the square of the radius; and it follows that the unit current must be defined as the current of which each centimetre exerts a force of one dyne on a unit magnetic pole at a distance of a centimetre.

The unit of electric quantity is defined as the quantity conveyed in one second by a current of unit strength.

It is found that the work required to transfer a given

quantity of electricity from one point to another of a conductor is equal to the product of the quantity transferred into the electro-motive force between the two points, and therefore the unit electro-motive force is an electro-motive force, such that, if it is established between two points, an amount of work equal to one Erg will be required to transfer the unit quantity of electricity from one to the other. The unit of resistance is then defined in accordance with Ohm's law, which asserts that the resistance between two points of a conductor is measured by the ratio of the electro-motive force between them to the current produced by it.

The unit of resistance is therefore defined as the resistance of a conductor in which unit electro-motive force produces unit current.

The units so obtained are not altogether of convenient magnitude for the expression of the electrical quantities which most commonly occur in practical work, some being too large and others too small.

The practical importance of selecting units of suitable magnitude may easily be seen by considering what would be the result if, on the one hand, drapers were to use a mile as the unit of length in selling silk to their retail customers; or if, on the other hand, the dates of events, referred, as is usual, to the beginning of the Christian era, were stated in seconds instead of years. The result would be that in the first case the quantities of silk most commonly sold would have to be expressed by means of decimal fractions of the unit; while in the second illustration the number of figures employed would be utterly unwieldy.

The units defined above, being based on the centimetre as a measure of length, the gramme as a measure of mass, and the second as a measure of time, are known as centi-

metre, gramme, second (usually denoted by their initial letters C.G.S.) units.

The practical unit of electric current is defined as one-tenth of the C.G.S. unit of current, and is called an Ampère, after the great French electrician of that name. The unit of electro-motive force is called a Volt, after Volta, and is taken to be a hundred million C.G.S. units. The unit of resistance, which is called the Ohm, is then defined as the resistance of a conductor through which an electro-motive force of one Volt will produce a current of one Ampère.

It can be shown to follow from these definitions that the Ohm is equal to a thousand million C.G.S. units.

The unit of quantity is called the Coulomb, and is defined to be the quantity of electricity carried by the unit current in a second. Its value is one-tenth of a C.G S. unit.

These units came into general use, in Great Britain and her Colonies, during the years 1870 and 1871, through the influence of the British Association Committee.

On the continent of Europe, however, the absolute system was not generally adopted for practical purposes until after the meeting of the International Congress of Electricians which was held in Paris in October, 1881, when it was decided that they should be adopted by electricians throughout the world.

The process of determining either the Volt or the Ohm in absolute measure is one of great difficulty, and requiring the most elaborate precautions. The result of this was that at the time of the Paris Congress numerous discrepancies existed between the experimental determinations of various eminent electricians, and it was therefore decided to define provisionally a "Legal Ohm" as the resistance of a column of pure mercury 106 centimetres long, and having a sec-

tional area of one square centimetre, this length being the nearest whole number to the mean of the most reliable of the results obtained. The Volt was therefore defined as the E.M.F. which maintains a current of an Ampère in a conductor whose resistance is a Legal Ohm. The Coulomb and Ampère retained their former definitions.

The unit of power employed by electrical engineers is defined electrically as the power developed in a circuit traversed by a current of one Ampère with a potential difference at its terminals of one Volt. This unit, which is called a Watt, is equivalent to ten million Ergs per second.

CHAPTER VIII

MAGNETO AND DYNAMO ELECTRIC MACHINES

WHEN Faraday had discovered that electric currents could be produced by the motion of a conductor in a magnetic field, he constructed a machine by which a continuous current could be conveniently generated in this manner. It consisted of a disk of copper twelve inches in diameter, and about one-fifth of an inch thick, fixed upon a brass axle, about which it was made to rotate with its edge between the poles of a large compound permanent steel magnet, formed by joining a number of steel horseshoe magnets together, the poles being about half an inch apart.

The current was made to pass through a pair of conducting wires or leads, one of which was attached to a brass axle, and the other to a copper strip, which rubbed against the edge of the disk between the poles of the magnet.

Faraday then found that, if a galvanometer was included in the circuit with conducting wires, a permanent deflection was produced, of an amount varying with the speed of rotation, and that it was reversed when the direction of rotation was reversed. This was the first magneto-electric machine. It was followed by a number of devices, in which coils of wire were made to rotate between the poles of a

permanent steel magnet; or in which the magnet was made to rotate, while the coils of wire remained fixed between the revolving poles.

Now, the use of steel magnets greatly restricted the power of these machines, for very large steel magnets are, in the first place, costly to build up, and, in the second place, they gradually lose a considerable portion of their magnetism.

In the year 1845 Wheatstone and Cooke took out a patent for the use of electro-magnets instead of permanent steel magnets, and three years later Jacob Brett suggested that the current generated in the armature by the permanent magnetism of the field magnets should be sent through a coil of wire surrounding the latter, so as to increase their strength.

This appears to be the first suggestion of the principle of the self-exciting dynamo.

In 1863 Wilde devised a machine in which an armature, consisting of coils of wire, was made to rotate between the poles of a large electro-magnet, which was excited by means of a separate small magneto-machine.

The term "dynamo-electric machine" was first introduced by Dr. Werner Siemens in 1867 in describing to the Berlin Academy machines in which currents were induced in the coils of the rotating armature by means of electro-magnets, which were themselves excited by the currents in the armature. This term, in its shortened form of "dynamo," is now employed for all electrical machines driven by mechanical power, whether self-exciting or not, in which the current is generated by the motion of coils of wire in a magnetic field, or by the rotation of a magnetic field about coils of wire. Since this time the theory and practice of

dynamo construction have advanced with rapid strides, and the various dynamos now in use are so numerous that they would require a volume very much larger than the present one for their description.

An ideally simple dynamo is shown in the illustration (Fig. 5).

It consists of a simple rectangular loop of wire rotating between the poles of a large magnet, and therefore, as has been pointed out before, in an approximately uniform magnetic field.

When the loop is vertical, as shown in the figure, it will be traversed from left to right by the maximum number of unit tubes of force; this number will diminish to zero when the plane of the loop is horizontal, and after another quarter revolution—that is to say, after half a revolution from its original position—the loop will again be traversed by the maximum number of unit tubes of force. They will now pass through it in a direction opposite to their former direction, owing to the aspect of the loop with respect to the magnetic field having been reversed. Starting from the position shown in the figure, the currents generated in the loop during the first half revolution will be all in the same direction. During the first quarter revolution the number of unit tubes of force passing through the loop will be diminishing, while, during the next quarter revolution, they will be increasing, and passing through the loop in the opposite direction, so that the effect will be the same. There will therefore be a current in one direction round the loop during

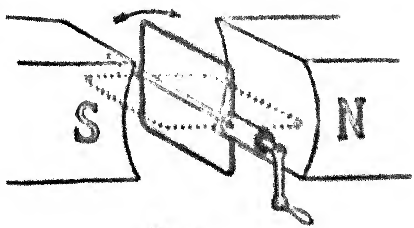


FIG. 5.

the first half revolution, and the opposite way round during the second half revolution. In order to send these currents through the conducting wires in the same direction, a commutator of the kind shown in Fig. 6 may be used. It consists of two nearly semicircular segments of metal tube mounted on a cylinder of hard wood or other convenient insulating substance. Each of these segments is connected with one end of the loop, and a couple of strips of metal are connected with the leads, and collect the current from the armature by pressing against the split tube, as shown in the diagram.

If the lines of force in the field were perfectly horizontal, these strips, or brushes, as they are called, would have to be set so as to reverse the connections as the plane of the loop passed through the vertical position; but it is found in practice that the brushes must be displaced slightly in the direction of rotation of the armature.

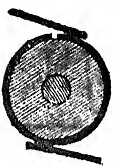


FIG. 6.

This displacement is called the lead of the brushes, and there has been considerable difference of opinion as to why it is necessary.

It is now known, however, that it is really due to the lines of force being turned into a slightly oblique position by means of the currents in the armature.

It is found that if a mass of iron is placed within the armature it will cause a large number of unit tubes of force to thread through the loop, the tubes which would otherwise pass outside the armature being attracted, as it were, by the iron, and made to pass through its mass.

When the field magnets are stationary and the armature is made to revolve, this mass of iron, or core, as it is called, should really be at rest, because if it rotates with the arma-

ture, currents will be induced within it, just as in the copper disk of Faraday's machine, and these, while absorbing some of the energy from the driving machinery, will not contribute anything to the current in the circuit.

It is, however, easy to see that there would be considerable structural difficulties to be overcome in fixing a stationary mass of iron within the revolving armature, and so it is usually made to revolve with the armature. In order to reduce as far as possible the currents induced in the core, and which are known as eddy currents, the cores are built up of thin sheets of iron, separated from one another by means of varnish, mica, asbestos paper, or other convenient insulating substance.

In addition to the waste of energy caused by these eddy currents, they heat the core considerably, and therefore, even independently of the waste of energy, solid iron cores are inadmissible, for the heating of the core which would ensue would not only increase the resistance of the armature coils, and therefore diminish the currents induced in them, but would destroy the insulating material which separates the different turns of the coils. In practice the armature is never formed of a single loop, but of a coil, such, for example, as is shown in Fig. 7, which exhibits a section of the original form of Siemens's shuttle-wound armature, consisting of a coil of wire wound upon an iron core. Siemens's original magneto-machine, with an armature of this kind, and permanent steel magnets, is shown in Fig. 8. This form of armature is still retained in small motors, but for larger machines it has been entirely replaced by armatures in which the coils are wound upon a ring or drum of iron, and which are therefore known as

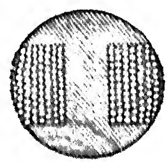


FIG. 7.

ring armatures and drum armatures respectively. Fig. 9 shows a simple ring armature with a single coil.

Now if a shuttle-wound, or a single ring-armature with

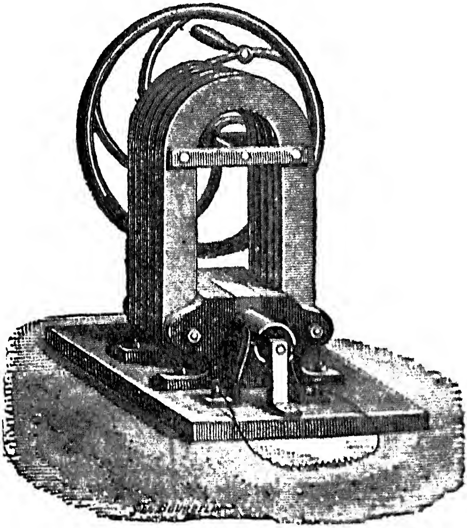


FIG. 8.

one coil, is employed, with a split tube commutator, although the currents in the leads will always be in the same direction, they will not be of constant strength, but will vary from a maximum to zero at each half revolution. To remedy this, the ring or drum-armature is made with a number of coils, and the tube of the commutator, instead of being divided into two segments only, is divided into as many segments as there are coils.

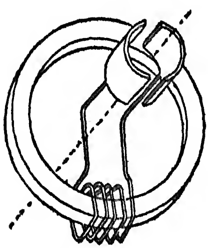


FIG. 9.

The coils of the armature then come into action in succession when they are in the position for best action. A ring-armature of this kind is shown in Fig. 10.

Here the armature coils are all in continuous connection; but in some machines, such, for example, as the well-known Brush machine, the coils are all separate, and each coil has its own commutator. A four-part drum-armature, with its commutator and collecting brushes, is shown in Fig. 11.

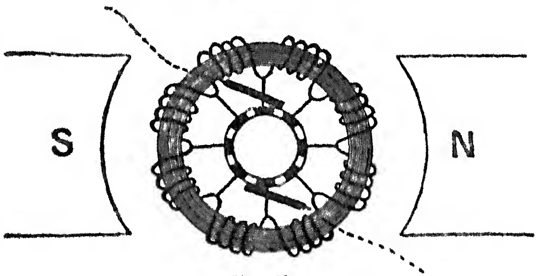


FIG. 10.

There are also disk-armatures, in which the coils are flattened against the disk, and pole-armatures, which have the coils wound upon separate poles projecting radially from the periphery of the disk, as shown in Fig. 12, which exhibits a six-pole armature with commutator and collecting brushes.

Methods of Exciting the Field Magnets.—There are five simple ways of producing the Magnetic Field in which the armature of the dynamo rotates. Of these methods the one first employed consists, as has already been pointed out, in the use of a permanent steel magnet. Fig. 13 shows, in a diagrammatic form, a machine of this kind with its circuit.

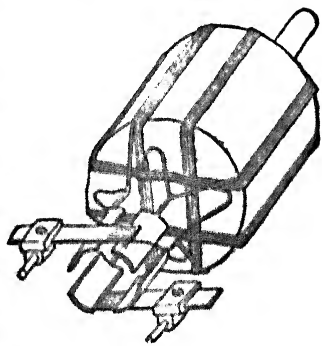


FIG. 11.

The terminals of the armature coils, together with the collecting brushes, are seen between the poles of the mag-

net; and the arrows show the direction of the current in the circuit when the armature revolves as indicated by the posi-

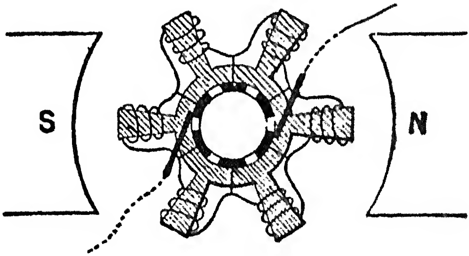


FIG. 12.

tion of the brushes—viz., in the direction of the hands of a watch. It will be seen that this is simply the old magneto-electric machine which formed the original of the modern dynamo; but as the latter is now adopted as a generic term for all these machines, I shall follow Professor S. P. Thompson in calling it a magneto-dynamo.

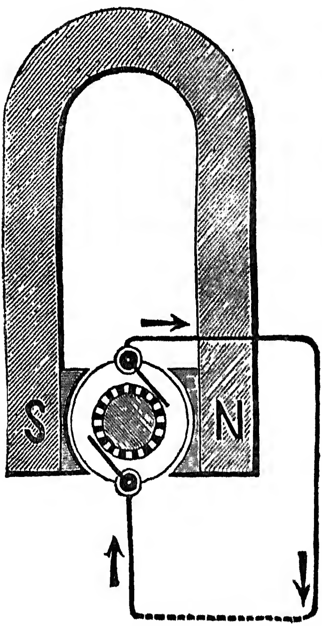


FIG. 13.

Permanent steel magnets are now only employed for quite small machines, numerous types of which, for laboratories and other purposes, are still made with them.

In order to regulate the E.M.F. produced by a machine of this kind a movable piece of iron is usually provided, which can be placed more or less over the poles of the Field Magnet, in such a way as to divert a certain portion of the magnetism from the armature.

The second stage in the development of the dynamo is shown in Fig. 14, which represents a separately excited dynamo—that is to say, one in which the magnetic field is produced by means of an electro-magnet, the magnetism of which is excited from some external source, such as a voltaic battery, or by means of a small auxiliary magneto-dynamo, as was done by Wilde in 1866.

The arrows in the diagram show the direction of the current in the field magnet coils required to produce the polarity indicated, and the direction of the current in the main circuit when the rotation is in the same direction as before. The separately excited dynamo may be governed in the same way as the magneto-dynamo; but there are two other methods of regulating its E.M.F., one or other of which will generally be found preferable. These consist either in weakening the current, which may be conveniently effected by introducing additional resistance into its circuit, or in altering the number of convolutions of wire through which the exciting current circulates round the field magnets.

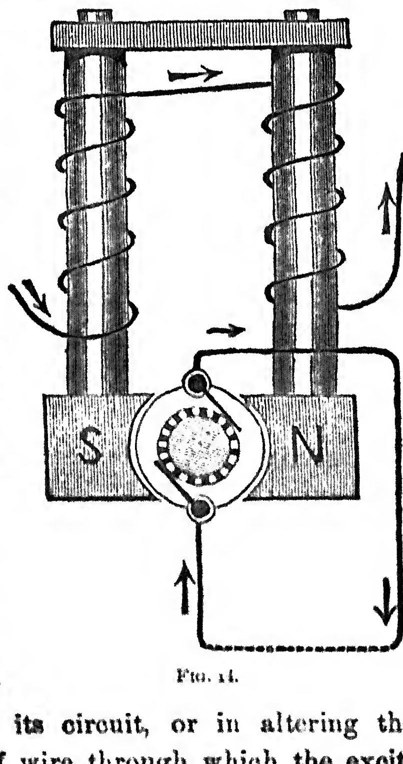


Fig. 14.

In any dynamo the magnetic field is necessarily modified by the current in the armature coils, the effect of the field

due to the armature being to produce an E.M.F. in the opposite direction to that due to the primary field, and therefore known as the back E.M.F.

It is evident that the strength of the back E.M.F. will increase with the speed of rotation, provided the resistance in the main circuit remains unchanged; but it will be diminished by increasing this resistance—that is, by giving the machine more work to do; for example, by putting a larger number of lamps into the circuit.

With the exception of the effect of this back E.M.F., it is clear that in both these machines the E.M.F. will be independent of the resistance in the main circuit.

The next stage in the development of the dynamo was to do away with the auxiliary exciter, and make the machine excite its own magnetism.

This is effected by making use of the current, or of a portion of the current, developed in the armature, to excite the field magnets. It would evidently be impossible to start this process unless the field magnets were excited to a certain extent to begin with.

Assuming this to be the case, it is easy to see that the small current which will be produced by rotating the armature may be made to increase their magnetism, and that the resulting increased strength of the magnetic field will increase the current through the armature, which, in its turn, will still further magnetize the field magnets; so that in this way, starting with a very small initial magnetization of the field magnets, it may be increased up to any desired extent below that of saturation. It is found in practice that this process can be started without initially magnetizing the field magnets from a separate source, the reason being that iron is always slightly magnetic; and although its residual

magnetism, as it is called, may be so small as to require exceedingly delicate instruments to detect it, it is invariably found to be sufficient, without external assistance, to start the process of self-excitation.

There are three simple types of self-exciting dynamo. The first and simplest of these, which may be called the ordinary dynamo, is known to electricians as the series dynamo. It is illustrated diagrammatically in Fig. 15, and it will be seen from the illustration that the whole of the current from the armature passes through the exciting coils, which are connected in series with the main circuit.

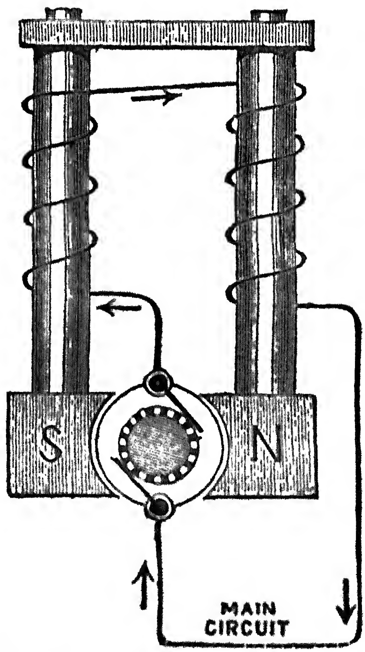


FIG. 15.

This form of machine has several serious disadvantages. In the first case, it is liable to become reversed in polarity, which makes it impossible to use it, either for electroplating purposes, or for charging accumulators or secondary batteries.

In the second place, it will not begin to excite itself until a certain speed has been attained, depending on the resistance in the circuit.

Finally, it has the disadvantage that any increase in the resistance of the main circuit diminishes the exciting current, and therefore diminishes the E.M.F. produced by the machine.

The serious nature of this last disadvantage will easily be understood by considering its effect when the machine is used to supply current for an electric light circuit. Arc lamps, such as are used for street lighting and for large interiors such as railway stations, are usually connected in series—that is to say, the main circuit wire is cut wherever a lamp is to be inserted, and the two free ends thus obtained are joined to the lamp terminals.

If additional lamps are put into such a circuit they will increase its resistance, and therefore diminish the power of the machine just when it ought to be increased. Incandescent lamps, on the other hand, such as are used for house lighting and in theatres, are usually connected in parallel—that is to say, the conducting wire joining the poles of the dynamo, and forming the main circuit, is continuous; and the direct and return portions of the conductor—or the positive and negative mains, as they are called—are connected across at various points through the lamps. In this case the addition of extra lamps to the circuit opens up additional paths for the electricity to traverse, and therefore diminishes the resistance in the circuit, so that a smaller E.M.F. is required to maintain the same current. The diminution in the resistance, however, increases the current through the field magnets, and this causes an increase in the E.M.F. developed by the machine.

In order to overcome some of the defects of the series dynamo, another type of machine, shown in Fig. 16, has been devised. In this machine, as is shown in the diagram, the field magnet coils are not connected in series with the main circuit; but their terminals, and those of the main circuit, are both connected directly to the collecting brushes. The two circuits are then said to be in parallel, and the

series coils are said to form a shunt to the main circuit; whence this form of machine is known as a "shunt" dynamo. The field magnet coils are made of a great number of turns of very fine wire, so that they have a much higher resistance than that of the main circuit, and are therefore traversed by a small portion only of the total current.

When a "shunt" dynamo is used to supply a current for a set of lamps in series, the addition of lamps to the circuit sends an additional proportion of the current through the field magnet coils, and thus increases the strength of the magnetic field, and therefore also the E.M.F. developed. If the machine is used to supply lamps in parallel, the resistance of the circuit is diminished, and less current is sent through the shunt coils, so that the strength of the field, and therefore the E.M.F. developed by the machine, is slightly diminished; and if the internal resistance of the armature is small, such a machine can be made to regulate itself fairly well.

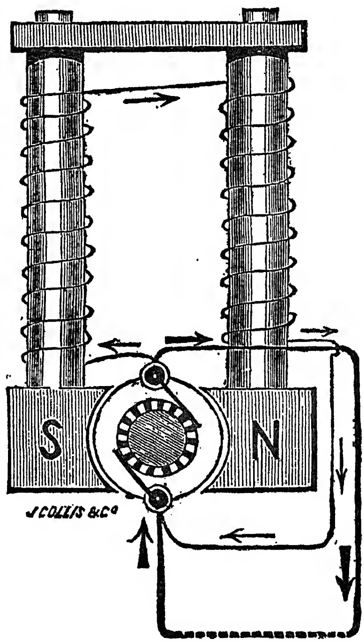


Fig. 16.

The principal objection to shunt wound machines is that any unsteadiness in the driving machinery produces a comparatively large effect on the main circuit. The reason of this is that the shunt coils, being formed of a great many

turns of thin wire very close together, and wound upon an iron core, have much more self-induction than the main circuit, and therefore any variation in the speed produces its effect upon the lamps before the current in the exciting circuit has had time to undergo a sensible change. Shunt dynamos are easily governed by introducing resistance into the exciting circuit.

The last of the simple forms of self-exciting dynamo is what Professor Thompson calls the separate circuit self-exciting dynamo. In machines of this type the "exciting" circuit is entirely separate from the main circuit, and the current through it is obtained either from a second armature spinning between the same field magnets, or through a special commutator connected separately with a few of the armature coils, and supplying no current to the main circuit.

Neither series nor shunt winding can be employed for alternating current machines, but either of the systems described may be employed in continuous current dynamos —viz., those which give a current always in the same direction.

In alternate current dynamos no commutator is required for transmitting the current to the main circuit, as the currents, rapidly succeeding each other in opposite directions, are sent through the circuit just as they are received from the machine, and therefore, with a rotating armature, a simple sliding contact is all that is required.

In some machines—such, for example, as those in use at the West Brompton Central Electric Lighting Station—the armature remains at rest and the field magnets are made to rotate; and in this case no sliding contact is required, the terminals of the main circuit being attached permanently to the armature. When the machine is a self-exciting one,

it is however necessary to employ a commutator to rectify the alternations in the exciting current.

The armature coils used for exciting the field magnets are therefore connected to a commutator, of which Fig. 17 represents a typical form. It consists of two hollow metal cylinders provided with teeth, and fixed upon a solid insulating cylinder, the teeth of either cylinder projecting between those of the other without touching them, as is shown in the illustration. The two collecting brushes are fixed so that one is always in contact with a tooth of one of these cylinders, while the second is in contact with a tooth of the other one. The two hollow cylinders form the terminals of the exciting coils of the armature.

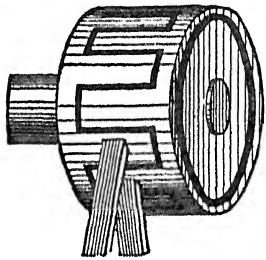


FIG. 17.

CHAPTER IX

THE STORY OF THE TELEGRAPH

SOME of the descriptions which have come down to us of the manner in which the decrees of the old Roman oracles were communicated to those who consulted them, irresistibly suggest that magnetism was one of the agents employed by the priests to deceive their dupes. The descriptions are naturally extremely vague, as the narrators themselves had no idea whatever of the process employed.

It is stated in one of these accounts that an iron tripod turned round in obedience to the incantations of the presiding priest, accompanied by certain movements, the object of which the narrator did not understand, of an iron ring suspended from a cord which the priest held in his hand. The letters of the alphabet, inscribed on separate small plates, were arranged round the tripod, and as the latter moved they were drawn down upon the table in such an order as to spell out the answer of the oracle.

It is very clear that these effects might be produced by means of magnetism, and it is difficult to imagine what other means could have been employed. It is moreover quite certain that the lodestone was known to the priests of ancient Egypt, and possibly through them to those of ancient Rome; and that the priests were also acquainted

with the fact neither member of the pair who had under-
and suspended so th.preparation wished to converse with his
would set itself pointing prick the letters upon his arm with

All through the Middle A spell out the message, and, as
as a means of imposition, both own arm, a corresponding
foretell the future, and by the quacks end.
sess the power of curing all the ills that almost impossible

Even the enlightenment of the nineteenth h statements,
not extinguished the latter class of impostors, and knowl-
therefore difficult to imagine how easily they could impacy
upon the credulity of the multitude in what are generally known as the dark ages. We learn again from many writers, beginning from an early date down to as late as the seventeenth century, that there was a widely-spread belief in the possibility of communication between distant friends by means of the magnet.

The method by which this was supposed to be effected usually consisted in balancing a pair of steel needles, which had been rubbed with the same lodestone, upon vertical axes resting on circular bases, round the circumferences of which were inscribed the letters of the alphabet.

It was then stated that if two friends each possessed one of these instruments, no matter how far apart they might be, they could carry on conversation by their means, the method of procedure being simply for the one who wished to speak to take his instrument and turn the needle in succession to the different letters, so as to spell out the sentence required, upon which, it was stated, the needle of the distant instrument would move from letter to letter in sympathy with the first. Such statements are, of course, absurd, and they probably originated in deliberate imposture with the object of obtaining money from the credulous

The famous philosopher Galileo tells us that he was sought out by one of these impudent impostors, who offered to sell him a secret art which would enable him, by means of the attraction of a certain magnetic needle, to converse across distances of several thousand miles. Galileo, however, was not the kind of man to be made a dupe, and he very pertinently suggested to the would-be vender that he should first put his art to the test by speaking from one corner of the room to the other. This, however, did not suit the impostor, who objected that the distance would be too short, and that the instruments would only work when the space separating them was considerable. Galileo then informed him that it was not convenient for him to travel into Egypt or Muscovy in order to try the experiment, but that if the adventurer cared to do so himself, he would remain in Venice and let him try to converse with him, promising that if the experiment were a success he would become the purchaser. It need hardly be said that the knave preferred to try his fortune elsewhere.

Another method appears to have been much believed in, but for obvious reasons it was not likely to be often put to the test of experiment. It consisted in cutting pieces of skin from corresponding portions, such as the arms, of two persons, and mutually transplanting them, when it was stated that each transplanted piece would grow to the new arm, which is quite possible, similar operations often being performed in modern surgery. The rest of the story however makes rather large demands upon our credulity. The transplanted piece of skin was said to retain so close a sympathy with its native limb as to be sensitive to any injury done to the latter. The letters of the alphabet were to be tattooed upon the transplanted pieces of skin,

and whenever either member of the pair who had undergone this previous preparation wished to converse with his friend, he only had to prick the letters upon his arm with a magnetic needle, so as to spell out the message, and, as each letter was pricked in his own arm, a corresponding pain would be felt in that of his friend.

It will perhaps appear to my readers almost impossible that any reasonable person could believe such statements, but, foolish as they appear in the light of modern knowledge, they are not more so than the belief in the efficacy of electric hair-brushes and magnetic lockets—*et hoc genus omne*—which not many years ago were offered for sale at almost every railway station in London; and when we find such absurdities as these being believed in by the masses, in spite of our present standard of knowledge, it becomes easier to understand how even learned men could believe the corresponding nonsense in vogue some few hundred years ago, when the standard of human knowledge was considerably lower than it is at present. These ideas, moreover, absurd as they are, are not without interest, as they seem to foreshadow, though in an impossible and ridiculous fashion, the magnetic telegraph now in use throughout the civilized world.

The electric telegraph, as it exists to-day, was of slow and gradual growth—so slow and gradual indeed that it is impossible to point to any one man as being the inventor of telegraphy.

If we follow the history of any scientific invention it will always be found that the process of development resembles the processes of nature in the organic world, and that though it may appear to flash suddenly upon the world, as Athene was said to have sprung, fully armed, from the

brain of Zeus, this sudden appearance is really only the advance into general notice of the results of long and patient but unobtrusive work; and just as the classic story appears to give a perfect analogue to the sudden appearance of a great invention in the public field of view, so on looking a little closer the analogy still holds; for before Athene sprang from the head of Zeus the latter had swallowed her mother Metis.

During the early part of the eighteenth century a good many philosophers occupied themselves with experiments in electricity, concerning themselves chiefly with the various means of producing it by friction. It was not, however, until the year 1729 that the discovery was made that some bodies conduct electricity freely and others only with difficulty. This discovery of the fact that substances can be divided, with respect to their electrical behavior, into the two great classes of conductors and insulators, was made in this year by Stephen Gray, a pensioner of the Charterhouse, and this observation was of such prime importance in the development of the electric telegraph that it may almost be regarded as its starting-point.

A great impetus was given to experimenting in electrical phenomena by Musschenbröck's discovery at Leyden in 1745 of what is now known as the Leyden jar; and experiments on the transmission of electricity which had been attempted before were now resumed with much greater success.

For example, in April, 1746, Abbé Nollet transmitted the shock of a Leyden jar through a number of Carthusian monks joined together by iron wires, and forming a circle five thousand four hundred feet in circumference. The contortions of the monks, when the circuit was closed,

were accepted as sufficient evidence of the shock having been felt throughout the whole circuit, and the fact that these contortions took place simultaneously showed that the time occupied by the electricity in traversing the circuit was too small to be perceptible.

The first actual suggestion of an electric telegraph was made in an anonymous letter published in the "Scots Magazine" at Edinburgh, February 17, 1753. The letter is initialled "C. M.," and many attempts have been made to discover the author's identity; but though plausible theories have not been wanting, the question has never been set at rest, and a considerable concurrence of evidence indicates that the author's reason for concealing his identity was his fear of being regarded as a magician by his neighbors.

The suggestions made in this letter were that a set of twenty-six wires should be stretched upon insulated supports between the two places which it was desired to put in connection, and at each end of every wire a metallic ball was to be suspended, having under it a letter of the alphabet inscribed upon a piece of paper. These pieces of paper were to be placed upon a horizontal table, at distances of about an inch below the balls.

Connection was to be effected by successively bringing the ends of the wires at the sending station into contact with the charged electrical conductor, in such an order as to spell out the message which was to be sent, and the message was to be read off at the receiving station by observing the letters which were successively attracted by their corresponding balls, as soon as the wires attached to the latter received a charge from the distant conductor.

In 1787 Monsieur Lomond, of Paris, made the very important step of reducing the twenty-six wires to one, and

indicating the different letters by various combinations of simple movements of an indicator, consisting of a pith-ball suspended by means of a thread from a conductor in contact with the wire, which was charged by being put in contact with a charged electrified conductor at the other end.

In the year 1790 Chappe, the inventor of the semaphore, or optico-mechanical telegraph, which was in practical use previous to the introduction of the electric telegraph, devised a means of communication, consisting of two clocks regulated so that the second hands moved in unison, and pointed at the same instant to the same figures, which were marked round the dials.

In the early form of the apparatus, the exact moment at which the observer at the receiving station should read off the figure to which the hand pointed was indicated by means of a sound signal produced by the primitive method of striking a copper stew-pan, but the inventor soon adopted the plan of giving electrical signals instead of sound signals, hoping in this way to be able to employ his apparatus for communicating at greater distances than would be possible when sound signals were used, as the slow rate at which sound travels would make the interval between the sending and receiving of the signal so great, that the hand of the clock at the receiving station would in the meantime have passed on to some other figure than the one intended to be indicated. He therefore used a Leyden jar discharge to give a signal, but he found it impossible, when the distance was at all considerable, to insulate his wires sufficiently well to transmit the signals, and it was this which led him to devise his well-known semaphore.

It was this difficulty of insulation which was fatal to all the telegraphic systems based upon the use of electric cur-

rents produced by frictional machines, or by the discharge of Leyden jars.

I pointed out in an earlier chapter that the electrical pressure, or electro-motive force, in the case of such currents is extremely high, while the quantity of electricity transmitted is extremely small, so that in order to transmit them through any considerable length of wire, the insulation must be exceedingly good, as otherwise the leakage would be so great that no perceptible quantity would reach the distant end. It would be quite impossible practically to obtain the insulation required for a line of any length, but it is quite a different matter for the telegraphs actually in use, whether the currents are obtained from voltaic batteries, or, as is occasionally done, from a small magneto-dynamo machine, for in this case a considerable quantity of electricity is transmitted at very low electrical pressure, and therefore on the one hand there is comparatively little tendency for the electricity to escape, and on the other hand, the quantity of electricity being large, a certain amount of leakage is comparatively unimportant.

The difference between the two cases is of very much the same character as that between conveying water in a pipe three or four feet in diameter, with a pressure equivalent to say ten feet of water, and carrying it through a pipe say an eighth of an inch in diameter, with a pressure equivalent to a height of several thousand feet of water. It is easy to see that in the second case the pipe would have to be enormously stronger than in the first, and that all the water would be lost if even a very small leakage took place, while in the first case a considerably greater leakage might take place without producing any sensible effect.

In 1795 Don Francisco Salva read a paper before the

Academy of Sciences at Barcelona which is of special interest in the history of Telegraphy, not only on account of the extent and completeness of his own designs, but also as foreshadowing a good deal of what was only carried out at a much later date. He suggested, in the first place, that instead of twenty-six wires being used, one for each letter, six or eight wires only should be employed, each charged by a Leyden jar, and that different letters should be formed by means of various combinations of signals from these. So far this was no advance on what had been done before, Lomond having already shown that it was possible to convey the signals by means of one wire only. He then, however, went on to explain that it would be exceedingly difficult to maintain even this number of wires if they were all separately suspended from poles, and he therefore suggested that they should be separately insulated, and then rolled together into a single cable, which is exactly what is done in London at the present day.

Salva tells us that in his first trials he made a cable of this kind by covering the wires with pitch coated paper, or some other dielectric, and then tying them together, and binding the whole with paper.

Salva therefore was the first to make an electric telegraph cable.

He also suggested that this cable should be laid in subterranean tubes, and that, in order to improve its insulation, it might be covered with one or two coats of resin. He further pointed out that the intervention of the sea need not prevent telegraphic communication between two places, for, as he tells us, it is not impossible to construct cables impervious to water, and to lay them along the bottom of the sea.

In the experiments by which Salva illustrated this paper

he did not adopt his own suggestion of using only six or eight wires, but employed seventeen double wires, one for each essential letter of the alphabet, those which are little used or whose power could be represented by others being omitted. Designs representing each of these letters were formed by means of a number of separate strips of tin-foil pasted on glass, and the two end strips of each letter were attached to the extremities of the corresponding pair of wires. A letter was indicated by taking the ends of the wires belonging to it and connecting them with the two coatings of a charged jar, upon which the observer at the distant station saw the letter illuminated by the spark passing across the breaks in the tin-foil. It is stated that this telegraph was actually employed over a distance of about a kilometre, the outgoing wires being all collected in one cable of the kind described, and the return wires in a second. A number of other attempts were made during the end of the last century and the beginning of the present one to devise a practically useful system of telegraphic communication by means of frictionally generated currents of electricity, and several inventors attempted to obtain the assistance of the Government in carrying out their projects, but they invariably received the stereotyped reply that "telegraphs of any kind other than those now in use are entirely unnecessary, as the Government are fully satisfied with the Semaphore system."

I must not, however, pass from this branch of my subject without giving some account of the work of Mr. (afterward Sir Francis) Ronalds, who took up the subject of telegraphy in the year 1816, and published an account of his experiments in 1823, in a little volume entitled "Description of an Electrical Telegraph, and of some other Electrical Appa-

ratus," of which the portion relating to the telegraph was reprinted in 1871.

Ronalds employed a single wire of brass or copper inclosed in thick glass tubes, and laid in wooden troughs lined inside and out with pitch, the different lengths of glass tubing being joined together by short overlapping tubes, sealed with wax, in order to exclude moisture.

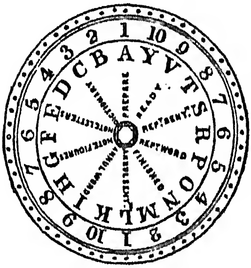


FIG. 18.

The receiving apparatus consisted of a circular brass plate, Fig. 18, divided into twenty equal parts, and rotated by clockwork, at the rate of one complete revolution per minute; each division carried a figure, a letter, and a preparatory sign. The figures were divided into two series each containing the numerals from one to ten, and the letters were arranged alphabetically, leaving out J, Q, U, W, X, Z.

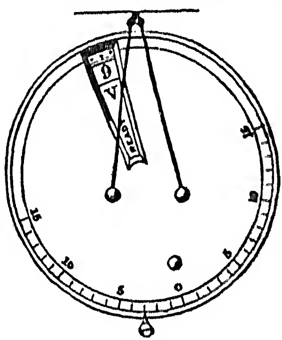


FIG. 19.

In front of this plate was fixed a second disk of the same size, provided with an aperture as shown in Fig. 19, and this disk could be turned by hand about its centre, which coincided with the first disk.

The aperture shown in the illustration was of such a size as only to allow one letter with its corresponding figure and preparatory sign to be visible at any one time. An electroscope, consisting of a pair of pith-balls attached by means of threads to a metal support in connection with the line-wire, was suspended in front of the latter disk.

The transmitting apparatus consisted simply of a small cylinder electrical machine, the prime conductor of which was in connection with the metal conductor from which the pith-balls were suspended, and through that with the line-wire. The transmitter and receiver at each station were exactly similar. When it was desired to send a message from either end, the outer disk was turned so as to exhibit the letter A with its corresponding numeral and preparatory sign, which, in this case, stood for the word "prepare."

The clock was then started, and a signal sent along the wire every time that the sign "prepare" came opposite to the aperture. The person at the receiving station in the meantime adjusted his apparatus so that the letter A was shown by his receiver at the moment when the signal "prepare" was sent through the wire, and, as soon as this had been done, he signalled the fact by sending a discharge at the moment that the preparatory signal standing for the word "ready" appeared opposite the aperture of his instrument. In this way the two dials were made to show the same letter simultaneously.

Ronalds drew up a sort of telegraphic code by which words, and sometimes even complete sentences, could be transmitted by only three discharges, and, in order to show whether letters, figures, or code-figures, referring to words and sentences in the dictionary, were intended, certain preparatory signs were made beforehand, such as "note letters," "note figures," "dictionary." Whenever a preparatory sign was to be read instead of a letter or figure, the fact was announced by sending an extra strong charge through the line, thus causing the pith-balls to diverge more widely than usual. In order to obviate the necessity of continually watching the instrument at each station, a small

Volta cannon was provided, consisting of a tube having its open end closed by a cork, and containing an explosive mixture of oxygen and hydrogen gases. A pair of wires in connection with the direct and return wires of the line passed through apertures in this tube, and came very close together without touching, inside it, so that when a dis-

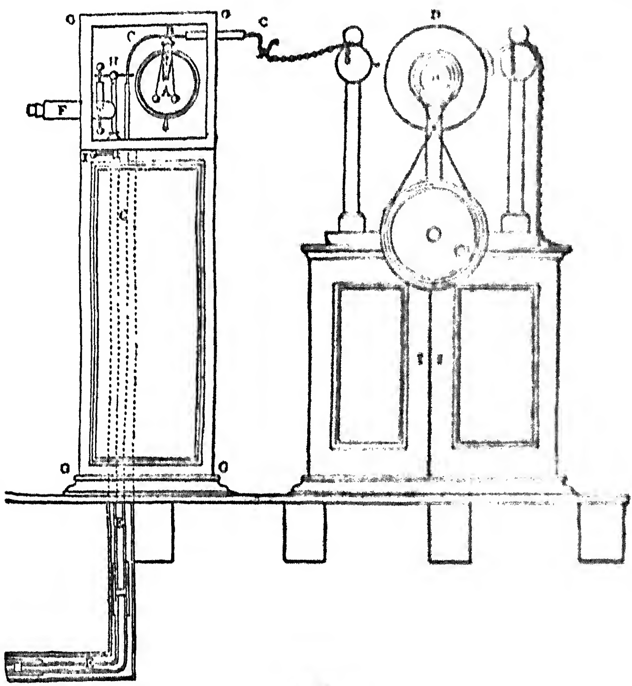


FIG. 20.

charge was sent through the line from the distant station, the gas was exploded, and, by its report, called the attention of the observer at that station.

The whole apparatus is shown in Fig. 20, D being the electrical machine, B the pith-ball electroscope, A the screen with its orifice, F the Volta pistol, and E the tube containing the conducting wires.

In the work previously referred to, Ronalds proposed that telegraph offices should be established throughout the kingdom. "Why," he says, "has no serious trial yet been made of the qualifications of so diligent a courier? and, if he should be proved competent to the task, why should not our kings hold counsels at Brighton with their ministers in London? Why should not our government govern at Portsmouth almost as promptly as in Downing Street? Why should our defaulters escape by the default of our foggy climate? and, since our piteous inamorati are not Alphei, why should they add to the torments of absence those dilatory torments, pens, ink, paper, and posts? Let us have electrical conversazione offices communicating with each other all over the kingdom if we can."

It would have been pretty well impossible to have made a more accurate forecast of the part now played by the electric telegraph in our daily life. The different residences of her Majesty are connected by telegraph wires with the government offices in Downing Street, and ministers can communicate with their subordinates, or be recalled upon occasions of emergency, from any part of the kingdom or from abroad. The telegraph has become one of the most efficient aids to the detective police force, and many a time has it happened that a thief or a murderer has succeeded in getting into a train for some distant seaport on his way to America or elsewhere, only to be stopped on arriving at his destination by detectives who had received his exact description by telegraph. If the criminal succeeds in getting out of the country, even if he goes as far as the Antipodes, he will generally find on arriving there that his description has preceded him, and he may not improbably be actually met on landing by the local police, who have received by telegraph

a complete description of him, together with the name of the ship in which he sailed. With regard to the "piteous inamorati," the post-office officials, if it were not for the regulation which compels them to maintain absolute reticence about the contents of all telegrams passing through their hands, would have amusing and sometimes pathetic accounts to give of the numerous messages which they have to transmit from love-sick swains and forlorn lasses.

The underground cable employed by Ronalds was not so very different from those which are now in use, though the India-rubber and gutta-percha now used as insulators are a great improvement on the glass tubes employed by him. Ronalds, however, pointed out that pitch and cloth might be employed as insulators, as had already been suggested by Cavallo; and tarred tape is still very largely employed, on the score of cheapness, where very high insulation is not required.

Ronalds, moreover, pointed out that cast-iron troughs might be made as tight as gas pipes if it were considered desirable to employ them, and the system of laying insulated telegraph wires in cast-iron pipes is one which is very extensively employed by the Post-Office at the present time in London. The tubes are usually laid down under the pavement, with openings at intervals, closed by movable covers, to enable defective wires to be removed, and new ones drawn in when required, without taking up the pipes.

Ronalds's remarks regarding the question of preserving the wires against malicious injury are so sensible and witty as to be worth quoting in full. "To protect the wires," he says, "from mischievously-disposed persons, let the two tubes be buried six feet below the surface of the middle of highroads, and let each tube take a different route to

arrive at the same place. Could any number of rogues then open trenches six feet deep in two or more public high-roads or streets, and get through two or more strong cast-iron troughs in a less space of time than forty minutes? For we shall presently see that they would be detected before the expiration of that time. If they could, render their difficulties greater by cutting the trench deeper, and should they still succeed in breaking the communication by these means, hang them if you can catch them, damn them if you cannot, and mend it immediately in both cases. Should mischievous devils from the subterranean regions attack my wire, condemn the houses belonging thereunto, which cannot easily escape detection by running away."

Ronalds proposed, moreover, in order that any breakage, whether accidental or otherwise, in the line might be immediately detected, to keep the line wire constantly charged with electricity, and to have certain testing stations established at convenient positions along the line, at which tests should be made at short intervals. This idea is almost exactly carried out in the telegraphs of the present day, except that Voltaic batteries are used instead of frictional machines to supply the current, and it is unnecessary always to keep the battery in circuit, the current only having to be turned on while the test is actually being made.

I must make one more quotation from Ronalds's work, as it shows that his insight into electrical phenomena enabled him to forecast a difficulty in the transmission of signals through long underground cables which no one else seems to have thought of—a difficulty which, in the early days of submarine telegraphy, proved to be a formidable obstacle in the way of the rapid transmission of signals through long submerged cables, and which was first explained with the

aid of mathematical analysis by Sir W. Thomson, and practically remedied by the beautiful signalling apparatus which he devised in accordance with the requirements indicated by theory.

Ronalds's statement is as follows: "That objection which has seemed to most of those with whom I have conversed on the subject the least obvious, appears to me the most important, therefore I begin with it, viz., the probability that the electrical compensation which would take place in a wire inclosed in glass tubes of many miles in length (the wire, acting, as it were, like the interior coating of a battery) might amount to the retention of a charge, or, at least, might destroy the suddenness of a discharge, or in other words, it might arrive at such a degree as to retain the charge with more or less force, even although the wire were brought into contact with the earth."

Ronalds completely proved the practicability of his plan, not only on the short underground line which I have described, but also upon an overhead line some eight miles in length, constructed by carrying a telegraph wire backward and forward over a wooden framework erected in his garden at Hammersmith; and although, when the electro-magnetic telegraph came into use, he freely admitted the great superiority of electro-magnetism for telegraphic purposes, yet he maintained to the last that if his own system had been tried on a large scale it would have been a practicable one, even for lines of many miles in length.

The first attempt to employ Voltaic electricity in telegraphy was made by Don Francisco Salva, whose frictional telegraph has already been referred to. On the 14th of May, 1800, Salva read a paper on "Galvanism and Its Application to Telegraphy" before the Academy of Sciences

at Barcelona, in which he described a number of experiments which he had made in telegraphing over a line some 310 metres in length. In these experiments he made use of Galvani's discovery of the convulsions produced in a frog's leg by means of electrical discharges, the motion of the frog's leg being employed to indicate the signals. In the course of these experiments, Salva discovered that the frogs at the distant station were sometimes thrown into convulsions, even when no frictional discharge was passing along the line, and he soon found that this was due to the slight Voltaic current generated by the contact between the frogs and the conducting wires at the sending station. This appears to have been the first discovery of the fact that the Voltaic current might be employed for the transmission of messages.

Salva continued his experiments in this direction, obtaining the electricity from a large number of frogs, and a few years later he applied the then recent discovery of the Voltaic pile to the same purpose, the liberation of bubbles of gas by the decomposition of water at the receiving station being the method adopted for indicating the passage of the signals.

A telegraph of a very similar character was devised by Sömmering, and described in a paper communicated by the inventor to the Munich Academy of Sciences in 1809. Sömmering used a set of thirty-five wires corresponding to the twenty-five letters of the German alphabet and the ten numerals.

These wires were connected to thirty-five gold points or pins which passed up through the bottom of a trough of water, and the letters and figures were indicated by connecting the terminals of the Voltaic pile to different

pairs of wires, when bubbles of oxygen and hydrogen respectively were evolved from the corresponding gold terminals.

In order to attract attention at the distant station, the gas rising in bubbles from two contiguous pins was allowed to collect under an inverted glass cup attached to the end of a long lever, and this lever, rising as the gas was liberated, caused a second lever to descend and throw off a small leaden ball resting upon it, which in falling set the clockwork of an ordinary alarm in motion.

Oersted's discovery of the action of the electric current upon a suspended magnetic needle provided a new and much more hopeful method of applying the electric current to telegraphy. The great French astronomer Laplace appears to have been the first to suggest this application of Oersted's discovery, and he was followed shortly afterward by Ampère, who in the year 1820 read a paper before the Paris Academy of Sciences, in the course of which he sketched out the plan of a telegraph in which the signals were to be indicated by small magnets placed under the wires.

In 1829 Professor Fechner, of Leipsic, pointed out that the effect at the distant station might be increased by inclosing the needles in coils consisting of many turns of wire, as Schweigger had already done in constructing his galvanometer.

In the following year Professor Ritchie, of the Royal Institution of London, adopted this suggestion and exhibited a model telegraph in which twenty-six separate circuits were employed with twenty-six suspended magnetic needles, each surrounded by a coil of wire. A much more practical form of telegraph was invented soon after

this by Baron Pawel Lwowitch Schilling. Baron Schilling's attention was first directed to telegraphy by seeing Sommering's telegraph in action in 1810 at Munich, Schilling being one of the attachés of the Russian Embassy at that place. Schilling's first electrical experiments were directed to the use of electricity for the purposes of war, and consisted of attempts to provide telegraphic communication between fortified places, and to explode powder mines at a distance by means of electric discharges carried through insulated wires laid under ground or under water.

The final form of Schilling's telegraph required a single metallic circuit only, consisting of a direct and return wire. The sending instrument was simply a key to make and break contact, or to reverse the current through the line. The receiving instrument consisted of a galvanometer formed of a magnetized needle, suspended, by means of a silk fibre, within a coil of wire in circuit with the line, the motions of the needle being indicated by means of a small disk of paper attached to the suspended fibre parallel to the needle, and painted white on one side and black on the other. In this way either the white or the black face was brought opposite the observer, according to the direction in which the current was sent through the line, and the different letters and other signs were indicated by means of various combinations of these two primary signals, for example, writing W for white and B for black; the vowels were indicated by the following combinations—A=bw, E=b, I=bb, O=bwb, U=wwb.

The first bi-signal alphabet is popularly supposed to have been devised by Morse, but as a matter of fact such alphabets were employed for signalling purposes as far back as the times of the ancient Greeks and Romans, the signals

consisting generally either of sounds, or signs visible at a distance. Schilling's device for attracting the attention of the observer at the distant station was very similar to that of Sömmering, upon which it was founded. The silk fibre by which the needle was suspended was replaced by a rigid metal wire carrying a horizontal metal arm, and when the needle was deflected by the current this arm struck against a delicately balanced lever, and caused a leaden ball resting on it to fall upon a second lever and set a clockwork alarm in motion, as in Sömmering's instrument. Schilling's telegraph is of special interest owing to its being the prototype of the modern needle telegraph instrument, and also because it was the immediate cause of the electric telegraph being introduced into England.

In 1833 a telegraph was constructed by Gauss and Weber at Göttingen for transmitting signals between their magnetic observatory and the physical laboratory of the University. This telegraph is principally of interest on account of the simple and ingenious method employed for increasing the sensibility of the receiving instrument, the plan being the same that was afterward adopted by Sir W. Thomson in his "Mirror" galvanometer.

The current was generated by an ordinary voltaic battery until the year 1835, after which a magneto-electric machine, made by Steinheil, was employed. The current produced by the magneto machine was made to deflect a large suspended magnet weighing about one hundred pounds, and as the deflections of this magnet were exceedingly small, they were observed by attaching a mirror to the magnet, and the deflections were read by placing, at a distance of ten or twelve feet, a telescope, at the top of which was fixed a horizontal scale, the reflection of the scale in the mirror

attached to the magnet being read off through the telescope. A "bi-signal" alphabet very similar to that of Schilling's was employed. The primary signals consisted of deflections of the magnet and mirror to the right and left respectively. Some kind of alarm was employed in connection with this telegraph, but the details of its construction have not been preserved.

Gauss believed that this telegraph was capable of being brought into a practical form suitable for general telegraphic purposes, but not being able to spare time from his scientific investigations to devote himself to the practical working out of the subject, he invited Steinheil to take it up, and this inventor introduced a number of modifications which vastly improved the original instruments of Gauss and Weber. In order to provide the current Steinheil employed a magneto-generator, consisting of a permanent compound magnet built up of seventeen horseshoe bars of magnetized steel, with a pair of coils, consisting of fifteen thousand turns of fine silk-covered wire, which were made to rotate between the poles, a commutator being provided to make the current continuous in direction. The coils were set in motion by means of a fly-bar terminating in two metal balls attached at right angles to the axis, about which they rotated. The receiving instrument consisted of a pair of magnets, to which were attached two cups, terminating below in fine perforated beaks, and filled with printing ink, so that each time the magnets, with the cups attached to them, were depressed, a dot was made upon a strip of paper carried under the cups by means of clockwork. The connections were made in such a manner that one of these magnets was depressed when the fly-bar made half a turn from right to left, and the other one when it made half a

turn from left to right. In some of Steinheil's receiving instruments the magnets, instead of being provided with cups, were made to strike upon two bells of different tones, so that Steinheil was the original inventor both of "printing telegraphs" and of "sounder receivers."

In the year 1838 Steinheil made, accidentally, the very important discovery that the return wire might be dispensed with, and the earth used to complete the circuit, so that only a single wire was necessary in order to effect communication between two stations.

Gauss had suggested that the two rails of a railway line might be employed as the conductors of a telegraph line, and in July, 1838, Steinheil tried the experiment on the railway between Nuremberg and Furth, but he was unable to insulate the rails sufficiently to transmit the current.

In making these experiments the great conducting power of the earth impressed itself forcibly upon his mind, and suggested to him that it might possibly be employed instead of the return wire, and he lost no time in putting the idea to the test of experiment. It was perfectly successful, and formed one of the greatest improvements in electric telegraphy, owing to the great reduction which it effected in the cost of erecting telegraph lines.

The next important step in the development of the electric telegraph was made by an Englishman, Edward Davy. It would take up too much space to give a detailed description of Davy's telegraph, as his system was developed without any knowledge of what other workers in the same field had been doing, and was consequently one of considerable complication. Two of his inventions, however, must not be passed over without notice—viz., the "Relay" and the

"Chemical Recording Telegraph," as they form important landmarks in the story of the telegraph.

The principle of the "Relay," or, as Davy called it, the "Electrical Renewer," though extremely simple, is one of very great importance, as it greatly reduced the difficulties incidental to long-distance telegraphy. The object of the relay is to obviate the necessity of using very large currents to compensate for the leakage inevitable in the case of long lines. The principle of the method consists in breaking up a long circuit between two distant stations into a series of shorter circuits, each complete in itself. Between each of these circuits is placed a relay, which is simply an apparatus, which, when a signal is sent from the transmitting station, makes connection between the next circuit beyond it and a local battery, and thus automatically carries on the signal.

In Davy's first relay the further end of the first line wire terminated in a rectangular figure of 8 coil fixed in a horizontal position. Within each coil was placed a needle, balanced upon a horizontal axis, and stops were placed to prevent each of the needles from moving, except in one direction. When a current was sent through the line, one or other of the needles was deflected, according to the direction of the current. The lower end of each needle carried a cross piece of copper wire, with its ends turned downward. One of these ends was always immersed in a cup of mercury, which was in connection with one of the terminals of a galvanic battery, and the other end was made to dip into a second mercury cup whenever the needle was deflected by a current through the coil. This second cup formed one of the terminals of the next circuit, which was in this manner put in connection with the battery.

In Davy's chemical recording telegraph, a strip of calico impregnated with Iodide of Potassium and Chloride of Lime passed over a copper cylinder, and was carried onward when the cylinder revolved. When a signal was sent from the transmitting station, a metallic contact piece, forming one of the terminals of the line, was made to press against the calico, which completed the circuit through the latter and the metallic cylinder over which it passed. Every time that a current was sent through the calico a mark was made upon it by the chemical decomposition of the salts with which it was impregnated, thus giving a permanent record of the signal. The metal cylinder was not made to revolve continuously, but, by means of a mechanism set in motion by the transmitting current, it was made to advance through a certain space after the transmission of every signal.

In the year 1834, Professor Wheatstone, a physicist of great eminence, was engaged in researches on the velocity of electric waves in solid conductors, and these experiments appear to have first directed his attention to the subject of electric telegraphy, in the development of which he played an important part. Very shortly after Wheatstone turned his attention to the subject of telegraphy, he associated with himself a Mr. Cooke, who had already been engaged in the construction of telegraph lines for railway purposes. Henceforth the two inventors worked together, and their labors are of special interest and importance, not only on account of the actual improvements which they effected, but because they were the first to establish the telegraph for practical purposes on a comparatively large scale, thus bringing it into much closer touch with the public than while it was confined to laboratory experiments, or to effecting scientific communications on a small scale, as in the case

of Gauss and Weber's telegraph perfected by Steinheil. The first joint invention of Wheatstone and Cooke consisted of a telegraph with five indicators and as many line wires. Its details were very carefully worked out, but practically it was inferior to that of Steinheil, and though it had a fair trial on the Great Western, and on the London and Birmingham Railways, it had to be given up on account of its heavy expense, due to the large number of line wires employed.

Wheatstone was thé first to contrive a really practical

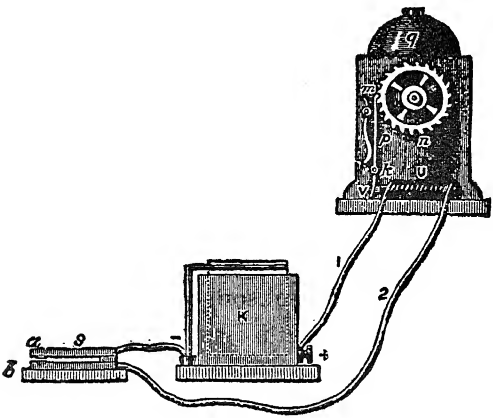


FIG. 21.

alarm for calling the attention of the observer at the receiving station. The arrangement of this instrument is shown in Fig. 21. It consisted of a clockwork alarm, previously wound up, and prevented from running down by means of a toothed wheel *n* resting against a lever *p*, the lower end V of which was made of soft iron, and formed the armature of the electro-magnet U. When a current was sent through the coil U the armature V was attracted, releasing the wheel and allowing the bell of the alarm to ring. The electro-magnet was placed in circuit with the line in the

manner indicated in the diagram, where 1 and 2 are the direct and return wires of the line, K is a battery, and *s* is a key consisting of two metal springs *a*, *b*, separated by a strip of ivory, the lower one *b* being mounted on a block of wood. The circuit was completed, and the alarm set in motion, by depressing the spring *a* so as to bring it in contact with *b*. Wheatstone, like Davy, experienced the difficulty of the weakening of the current by the resistance of the line and apparatus, and by leakage, due to imperfect insulation, and he remedied it in a similar manner by means of a relay which introduced a local battery into the circuit.

Another inventor whose name is now well known in telegraphy was Morse, an American artist, who is said to have first conceived the idea of an electro-chemical telegraph in the year 1832 while on his homeward voyage from Europe. He received considerable assistance in his first attempts in this direction, and also in his subsequent experiments, from a fellow-passenger—Dr. Jackson, of Boston—who had a considerable acquaintance with electricity and chemistry, and who had seen a good many experiments in telegraphy carried out in Paris. In the first apparatus constructed by Morse, the signals were recorded by passing the current, by means of platinum contact points, through paper moistened with acetate or carbonate of lead; or impregnated with turmeric, and moistened with a solution of sulphate of soda.

The subject of electric telegraphy had by this time attracted the attention of numerous scientific and practical men, but space will not allow of my discussing in detail their various contributions to the subject; I will therefore conclude the story of the telegraph at this point, reserving for the next chapter the description of the more important telegraphic apparatus now in use.

CHAPTER X

OVERLAND TELEGRAPHS

WHEATSTONE AND COOKE'S SINGLE-NEEDLE TELEGRAPH.—In this instrument the letters of the alphabet are indicated by motions to right or left of a small pointer or needle capable of moving a short distance between two fixed stops. The pointer, with its dial and the signs corresponding to each letter, is shown in Fig. 22; the two stops are shown in the diagram on either side of the upper portion of the needle. In the first instrument made by Wheatstone and Cooke five needles or pointers were employed, which were afterward reduced to two, and finally to one. A few double-needle instruments are still in use on some of our railways, but they are rapidly being replaced by single-needle instruments, which are much more convenient.

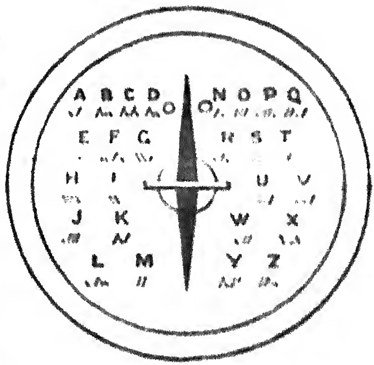


FIG. 22.

The construction of the single-needle instrument is shown in the accompanying diagrams. Fig. 23 shows

a front view of the instrument with the cover and dial removed. Fig. 24 shows a side view of the interior, and Fig. 25 shows a horizontal section of the commutator, or

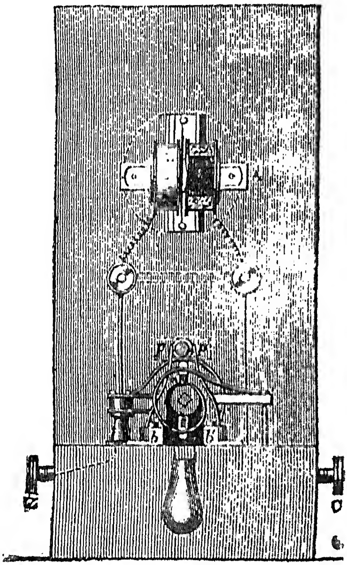


FIG. 23.

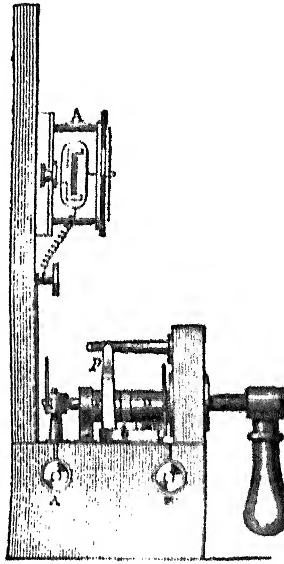


FIG. 24.

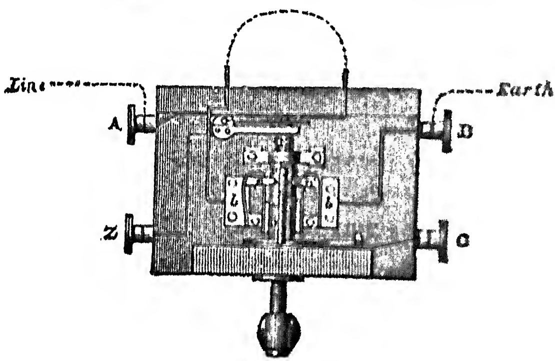


FIG. 25.

sending arrangement. Corresponding parts are indicated by the same letters in all the three diagrams.

The upper portion of the apparatus marked A in Fig.

23, is the receiver. It is formed of two ivory bobbins, wound with fine, silk-covered wire, and placed on opposite sides of a small magnetic needle attached to the pointer of the dial, and free to move within the bobbins to the right or left until arrested by the stops; one end of each bobbin is connected to the line, and the other to the earth.

The signals are given by passing a current through the coils by means of a battery at the sending station, or from a local battery, the circuit of which is closed by a relay actuated from the sending station.

The wire from the copper pole of the battery is attached to the binding screw C, and that from the negative or zinc pole to the binding screw Z; the binding screws A and B are connected with the line and with the earth respectively. The axle DF of the commutator is made in two parts D and F, of gun-metal, separated by some insulating substance, boxwood being the one most generally employed. D is connected by a wire to C, and F to Z.

A steel spring p is connected by means of a brass bar, b, through the coils and the receiver, to the terminal A; and a second steel spring p' is connected by means of the brass bar b' with the terminal B.

When the needle is in its normal or vertical position these two springs rest against a projecting pin shown in the diagram, and thereby maintain the continuity of the line.

From the upper side of the gun-metal F, and from the lower side of the gun-metal D, project two metallic pins, m, m'. When the handle is in its moral position the pin m remains between the spring p and p', without touching either; and the pin m' similarly remains between the brass bars b and b', without touching them.

When the handle is moved to the left, the pin m' comes

in contact with the brass bar *b*, and is therefore connected through the spring *p* with the terminal A, connecting the positive pole of the battery to the line-wire; at the same time the pin *m* is made to press against the spring *p'*, and therefore connects it, through the brass bar *b'*, with the terminal B, connecting the negative pole of the battery to the earth; and a current is therefore sent round the line-wire in a certain direction and deflects the needle. If the handle is turned to the right, *m'* comes in contact with *b*, and connects the positive pole of the battery to earth while, *m* is pressed against *p*, and connects the negative pole with the line; so that a current will be sent round the line in the direction opposite of the former one, and the needle will be again deflected. If the first current deflected it to the right it will now turn to the left, and *vice versâ*.

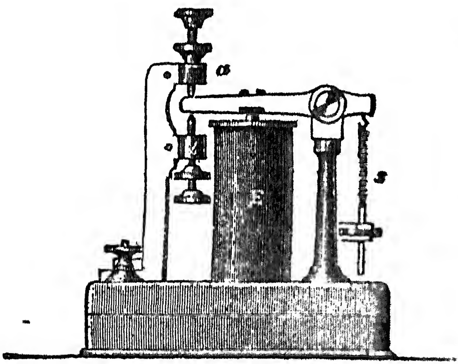


FIG. 26.

In the needle-instrument the signals are discerned by means of the eye. Audible signals are now very largely used in place of visual ones, an instrument called a sounder being most generally used; but a pair of bells, giving two distinct tones, are sometimes employed.

The Sounder.—The sounder in general use in this country is shown in Fig. 26. E is an electro-magnet formed of an upright rod of soft iron surrounded by a coil of silk-covered wire, with an outer covering of India-rubber, or some other substance, to protect it from injury. The ends

of this coil are connected through a pair of terminals attached to a wooden base—one only of which is shown in the diagram—to the line-wire and to the earth respectively. The armature of the electro-magnet consists of a bar of soft iron movable about a horizontal axis between two stops, *a* and *b*.

When the circuit is open the armature is pressed up against the stops by means of the spring *s*, the tension of which may be varied at pleasure, according to the strength of the current in the line-wire, by means of the adjusting screw shown in the diagram. When the circuit is closed, by means of a key at the transmitting station, a current is sent through the coil of the electro-magnet, which magnetizes it as long as the current is passing, and therefore pulls down the armature against the stop *b*. The sounds are made by the armature striking against the stops; and the letters of the alphabet are denoted by various combinations of long and short signals respectively, known as dots and dashes, separated by intervals of silence, or spaces. The dots are formed by giving a sharp stroke to the key; the dashes, by depressing it more slowly.

It is evident that considerable practice would be required before an operator would be able to transmit or to read off signals of this kind satisfactorily, but practiced operators are able to transmit and receive messages by means of this instrument with extraordinary rapidity.

In the system of signals employed, a dash is considered to be equal to three dots, and there are three kinds of spaces employed—viz., a space equal to one dot between the different elements of a letter, a space equal to three dots between the different letters of a word, and a space equal to six dots between two words. The letters E and T, being those

mostly used, are represented by a single dot, and a single dash respectively, and the other letters, numerals, and stops are formed of combinations of these.

The key employed in sending the message is shown in its simplest form in Fig. 27. It consists of a brass lever K in permanent connection with the line-wire, and movable about a horizontal brass axle fixed upon an insulating support of wood or ebonite. It is maintained in its normal position, viz., in contact with the stop 3, by means of a

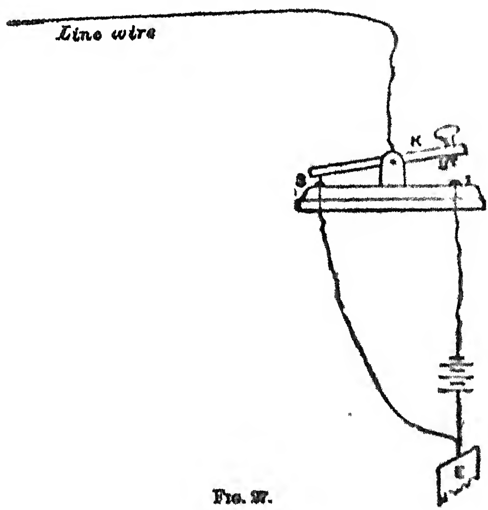


FIG. 27.

spring, not shown in the figure, and thus keeps the line-wire in connection with the earth.

When the key is depressed 2 is brought into contact with 1, and the current from the battery, shown in the diagram by the ordinary conventional sign, consisting of a series of long thin lines and short thick ones parallel to each other, is sent through the line.

It is evident that the duration of the current will depend upon the length of contact, and, to use an illustration due

to Mr. Preece, dots or dashes can be sent by striking the key exactly as one would the keys of a piano in order to produce crotchets or quavers respectively. Another form of sounder, which is extensively used in America on railways, and in other places where external noises are liable

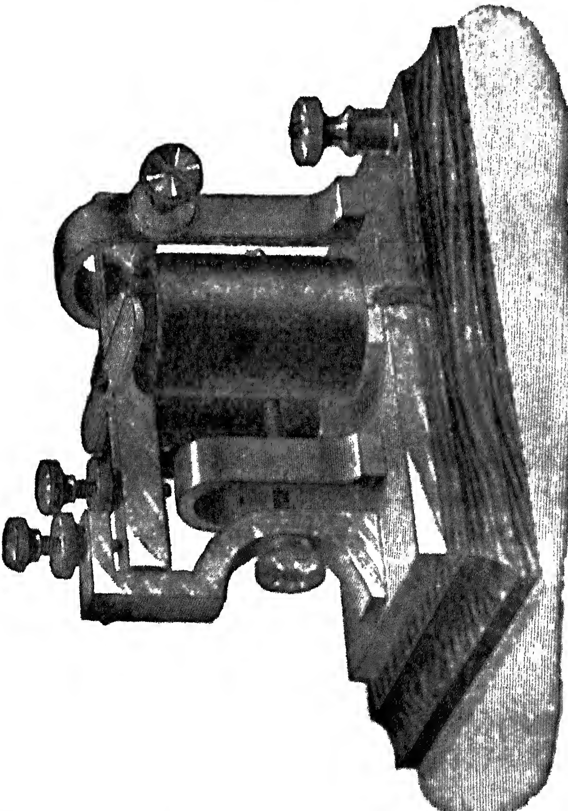


Fig. 28.

to interfere with the sound of the instrument, is shown in Fig. 28. This instrument has a very heavy armature lever, and the downward stroke of the armature takes effect upon an arc or bridge, as shown in the illustration, thus considerably increasing the volume of the sound.

When the line is of any great length, the imperfect insulation will make the current too weak to work a sounder without the use of a relay, the principle of which was described in the last chapter.

In its present form it consists simply of a more delicate form of electro-magnet than the one employed in a sounder. It is wound with a very large number of turns of fine wire, so as to enable the weak current to produce as great a magnetizing effect as possible upon the core, and its parts are very delicately constructed, so that a very small force is sufficient to move it. In the simplest forms of relay the armature is of soft iron, just like that of the electro-magnet

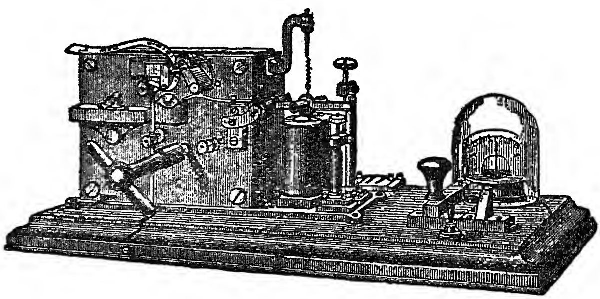


FIG. 29.

of the Morse sounder: these instruments are called non-polarized relays to distinguish them from polarized relays, in which the armatures are either permanent magnets, or are maintained in a magnetized condition by means of permanent magnets fixed in their immediate neighborhood. Polarized relays are affected by the direction of the current, and they can be made much more sensitive than the non-polarized ones. For this reason the latter instruments are very seldom used in this country.

The Morse Ink-Writer.—This is an instrument of an entirely different type from the needle telegraph and the

sounder, in that it gives a permanent record of the messag sent. A general view of one of these instruments is show in Fig. 29, and the electrical portion of the apparatus shown diagrammatically in Fig. 30.

E is an electro-magnet, of the same character as that employed in the sounder, and is worked in a similar manner by means of a key from the transmitting station. F is a sof iron armature attached to the lever *f*, movable about a hori zontal axis, as shown in the diagram. When no current is passing through the apparatus, the lever *f* is kept pressed against the stop 2, by means of the spring S, the tension o

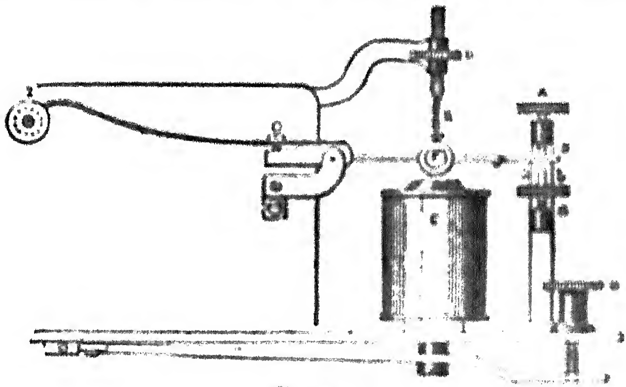


Fig. 30.

which can be regulated by the screw C. The farther ex tremity of the lever carries a small disk I, movable about a horizontal axis, and dipping into a reservoir of ink. The paper is carried through the apparatus by means of an ordi nary clockwork arrangement, in the direction shown in Fig. 29, and this clockwork also keeps the disk I in rotation, and thus insures its being kept wetted with ink.

When a current is sent through the apparatus from the line, the armature F is attracted toward the electro-magnet until the lever *f* strikes against the stop 3, causing the disk

I to come in contact with the paper and record a dot or a dash, according to the time during which the transmitting key is depressed. The play of the lever *f* can be adjusted by means of the screws A and B, and the screw G serves to adjust the position of the inking disk I, while the attractive force between the armature and the electro-magnet E can be varied by raising or lowering the coils by means of the screw D.

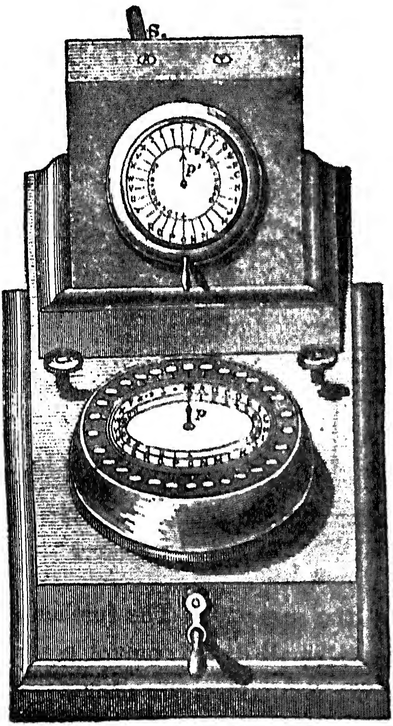


FIG. 81.

Wheatstone's A B C Instrument.—This instrument is a very good type of a considerable number of telegraph instruments, in which the signals are recorded by means of a pointer moving round a dial on which the letters of the alphabet are marked. Siemens, Breguet, and others have invented instruments of a similar character, but Wheatstone's is the form usually employed in England.

An A B C telegraph is very suitable for use on private wires, where great rapidity is not requisite, as it can be worked by any person of ordinary intelligence without previous practice. Fig. 81 gives a general view of the instrument.

When the handle shown in front is rotated, a soft iron

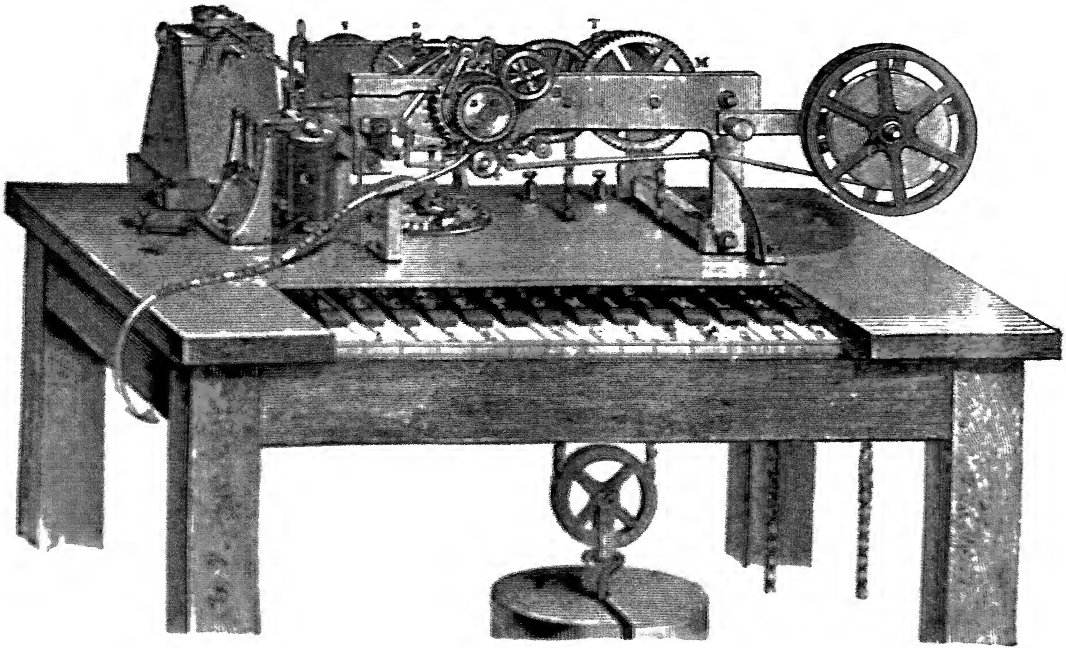


Fig. [illegible]

armature is made to spin in front of a pair of coils surrounding the poles of a horseshoe magnet, thereby generating at each revolution four currents in alternate directions through the coils, and by means of suitable mechanism each current is made to move the pointer through one space. In order to indicate any letter, the key opposite to the required letter on the lower dial is depressed, and the handle turned until the pointer p comes opposite to that letter.

When this takes place p is prevented from turning further, and at the same time the currents, instead of going into the line-wire, are cut off, so that p, and the pointer p' on the indicating dial at the receiving station, remain pointing to the same letter.

Hughes's Type-Printing Telegraph.—A good many instruments, some of exceeding ingenuity, have been devised, in which the message is directly printed off in ordinary type, just as if it had been done by means of one of the typewriters now in general use. The only one of these that has been employed to any considerable extent in Europe is that of Hughes, a general view of which is shown in Fig. 32. The instruments at the transmitting and receiving stations are exactly similar, and are made to move in perfect synchronism; and each letter is registered by means of a single current of short duration, which at the right moment brings a strip of paper, carried underneath the type-wheel, in contact with the wheel a, at the edge of which are placed the letters of the alphabet, so that the required letter is printed upon the strip as the type-wheel is made to revolve by means of suitable mechanism. The messages are sent by depressing a series of keys marked with the different letters and numerals, as shown in the illustration.

When a key is depressed it raises a pin, and this pin catches the chariot A, which rotates the type-wheel, and sends a current to the distant station, causing the paper at both stations to be pressed up against the type-wheel at the same moment.

The Wheatstone Automatic Telegraph.—With the instruments previously described the signals have to be transmitted directly through the line by means of an instrument worked by hand, and the greatest speed attainable does not exceed thirty or thirty-five words per minute. In addition to this, an operator working for some hours at his maximum

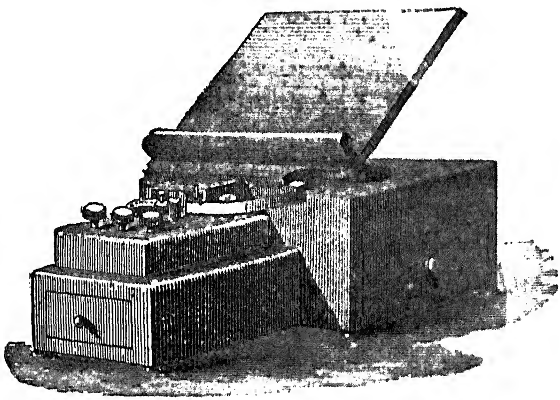


FIG. 33.

speed will naturally become tired, and therefore not only will the speed at which he can work be gradually reduced, but errors are very likely to be made. Now Morse signals can be sent along a line and recorded by an ink-writer at a very much greater rate than any clerk can send by hand; hence many attempts have been made to devise some means of transmitting messages automatically, and the system most generally employed in England is that invented by Wheatstone.

Wheatstone's automatic telegraph consists of three distinct parts—viz., a perforator, which prepares the message by punching holes in a paper ribbon; a transmitter, which sends the message from the line by means of automatic machinery, controlled by the punched paper which is passed through it; and a receiver, which records the message. The general appearance of the perforator is shown in Fig. 33.

It will be seen that there are three keys in the front portion of the apparatus, and each time that one of these keys is struck it actuates a mechanism which causes a paper ribbon to move forward through a definite space, and at the same time actuates one or more of a series of five punches, shown at 1, 2, 3, 4, 5, in Fig. 34. When the left-hand key

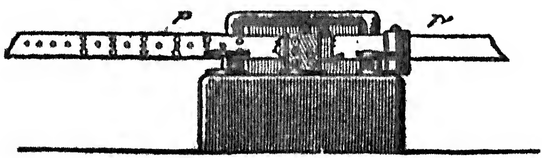


Fig. 34.

is struck it causes the punches 1, 2, and 3 to perforate the paper, punching out three clean round holes in a vertical line; the centre key actuates the punch 2 only, making a single hole, while the right-hand key depresses the four punches 1, 2, 4, and 5. The punches are usually struck with small wooden mallets held in the hands. The series of holes made by the left-hand key corresponds to a dot, the single hole made by the centre key to a space, and the set of four holes made by the right-hand key to a dash. The holes made by the centre key are in the centre of the ribbon, as shown in Fig. 34, and they are smaller than the upper and lower holes.

A small toothed star-wheel, which turns through a defi-

nite space when a key is depressed, fits into these holes, and moves the paper a step onward at each depression. It will be seen that for each dash two central holes are punched, so that the paper will move twice as far for a dash as for a dot. Fig. 35 shows a strip of paper thus prepared to indicate the word "Paris," by means of dots and dashes, as shown on the lower part of the strip in the diagram.

The transmitter is a very complicated piece of apparatus, which is made to send a series of currents in opposite directions into the line under the control of the punched paper. The strip of paper is carried through the instrument by means of the star-wheel working into the central row of

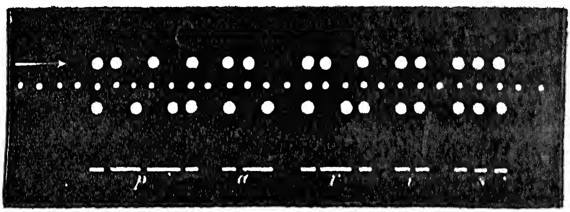


FIG. 35.

holes, and two vertical rods are pressed upward against the ribbon by means of springs, and are placed in such positions that they will enter the two outside series of holes as they pass above them. The rods work a disk which acts as a commutator, each entry of the rod into a hole on one side of the ribbon sending a current through the line in one direction, and each entry of the rod into a hole on the other side of the ribbon sending a current in the reverse direction. The punching which corresponds to a dash reverses the current after an interval twice as long as when the holes punched correspond to a dot. If there were no paper in the instrument the rods would move up and down alternately.

When one of the rods has entered a hole, as the instrument continues to move it is drawn out, and the paper moved on either through one or two spaces, according to whether a dot or a dash is to be sent when the other rod next enters a hole.

This transmitter will work at a speed of 450 words a minute on a short line, but more slowly over a long line, owing to the wire becoming charged very much like a Leyden jar. The amount of this electro-static charge depends on the length and surface of the wire and its distance from the earth, as well as on the nature of the insulating material, whether simply air, or partly India-rubber or gutta-percha, which separates it from the earth. The result of a portion of the current being absorbed in producing this electro-static charge is that a momentary current, such as would be produced by simply touching the key and raising the finger immediately, would produce little or no effect at the further end of a long telegraph line, and therefore the instrument has to be worked more slowly as the line increases in length.

The receiver employed with the automatic transmitter is simply a Morse ink-writer of a more delicate and sensitive character than the one already described. With a Wheatstone automatic instrument a number of clerks can be employed to punch strips corresponding to the messages, and these can be run rapidly one after the other through the transmitter, thus greatly reducing the number of lines necessary between two places where the traffic is heavy.

Another way in which the capacity of a line can be increased consists in employing an arrangement by means of which two or more sets of messages can be sent simultaneously in opposite directions along the same wire without

interfering with each other. The arrangement adopted for sending two messages simultaneously is called *duplexing* the line, and it will be of interest to describe briefly one among the various methods by which this is effected.

Duplex Telegraphy.—Let two stations, A and B, be connected together, as shown in Fig. 36, in which P, P′ represent receiving instruments, or relays working receiving instruments, and K, K′ are the transmitting keys at the two stations. It will be seen that the line is carried from the earth, E, through an adjustable resistance, R, along the path, *c*, *a*, *C*, *C′*, *b*, *c′*, to a second adjustable resistance, R′, connected with the earth at E′. The resistances R and R′ are

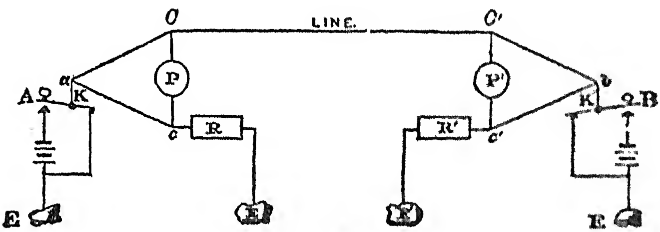


FIG. 36.

made equal to that of the line at the time of working, *a C* and *a c* are two fixed resistances equal to each other, as also are *b C′* and *b c′*.

The line is earth connected at *a* and *b*, by means of the keys K and K′, either directly, or through the corresponding battery, according as the key is in its normal position, or is depressed. When the key K is depressed, a current is sent from the battery through the point *a* where the line divides, part going along the line *a C C′ b c′*, and to earth at E′, while the other part goes to earth at E by the path *a c* E. Since the resistance of *a C* is equal to that of *a c*, the electro-motive force produced at *a*, by means of the

battery, will produce the same potential at the points *C* and *c*, and therefore no current will flow along the path *C* P *c*, so that the instruments at P will not be affected by any motions of the key K, which, however, will affect the instruments at P′. In the same way the current sent from B, by means of the key K′, will affect the instruments at P, but will have no effect upon those at P′.

Not very long after Duplex Telegraphy was first introduced by Gintl, of Vienna, it was extended by Edison so as to enable two sets of signals to be sent simultaneously in opposite directions, forming what is known as "Quadruplex Telegraphy."

This was still further developed by Delany into the system of "Multiplex Telegraphy," by which three or more sets of messages can be sent at the same time in opposite directions along a single wire.

The Writing Telegraph.—I must not conclude the description of modern telegraphic apparatus without mentioning a very interesting telegraphic instrument of recent invention—viz., the Writing Telegraph of Mr. J. H. Robertson. By means of this instrument a message written by an operator at the sending station on a slip of paper, carried along at a uniform rate by means of clockwork, is reproduced in facsimile at the receiving station. This was not the first writing telegraph, as one of a somewhat similar character was invented by Mr. E. A. Cowper; but Cowper's was not a form suitable for practical use. Robertson's instrument, on the contrary, can be, and is actually, employed for practical purposes in America, though hitherto the post-office monopoly has prevented its use in this country. It requires two circuits for each pair of instruments, or the equivalent of two circuits—viz., a single circuit duplexed.

The transmitter of the writing telegraph, shown in Fig. 37, consists of two piles of disks of exceedingly fine compressed carbon, placed with their axis at right angles, and each pile is provided with a screw for regulating the pressure between the disks. The two piles form portions of the two circuits required to connect the transmitting with the receiving station, one pile being contained in each circuit.

The transmitting pen consists of a rod, shown in the diagram, which is pivoted at its lower end between the two piles, and is provided with pressure points, which exert a varying pressure upon one end of each pile of disks when the rod is moved about in any manner. The motions of this rod are effected by means of the stylus pivoted to its upper extremity.

When the instrument is put together ready for use, the rod passes through a small square hole in the top of the case, and the operator writes by moving this stylus just as he would a pen.

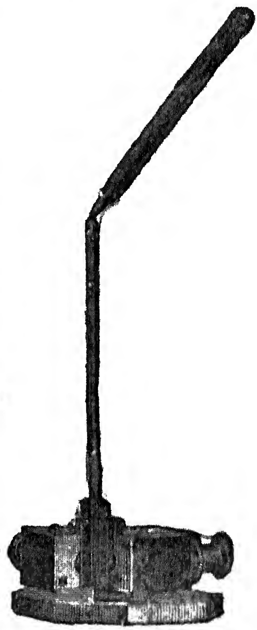


FIG 37.

As the pressure points of the transmitting-rod press more strongly against either pile of carbon disks, the contact between the separate disks in that pile is improved, and therefore the electrical resistance of the corresponding circuit is diminished, and the current in it therefore increased.

The receiving apparatus consists of a pair of electromagnets arranged at right angles to each other, as shown in Fig. 38. The armatures of these magnets are attached to

a rod, pivoted at its lower extremity between the adjacent poles of the electro-magnets, as shown in the diagram. The pen of the receiver is similar in principle to the well-known stylographic pen, and is attached, as shown, to the upper extremity of the armature rod. The coils of one of the electro-magnets of the receiver form a portion of the circuit containing one of the sets of carbon disks, while the coils of the second electro-magnet are included in the circuit containing the other pile of disks. As the transmitting stylus is moved, the resulting continuous variation in the strength of the currents in the two circuits causes a corresponding continuous variation in the attraction exerted by the two electro-magnets respectively upon their common armature, and in this manner the rod carrying the pen is made to move in a path exactly similar to that of the transmitting rod.

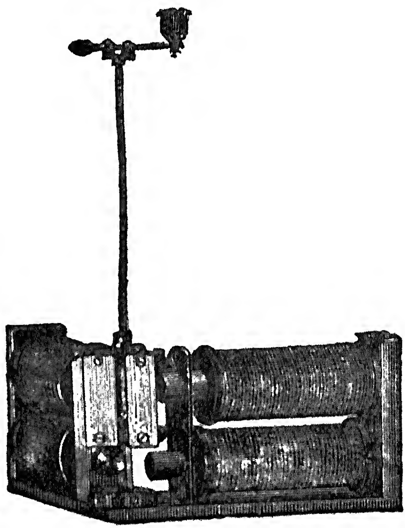


FIG. 38.

In the original form of the instrument the pen by which the message was written at the transmitting station was rigidly attached to the transmitting stylus, but this pen was afterward done away with.

As the operator at the transmitting station moves his stylus, his own pen, in circuit with the line, travels over the paper ribbon of his own instrument, moved forward at a uniform rate by clockwork, in obedience to the motions of the stylus, thus enabling him to see what he is writing,

struts, the lower portions of which are buried in the ground at some distance from the base, while the upper ends are attached to the poles.

In this country the wires are generally insulated by being fixed to porcelain cups attached to the poles. The cups are made of such a form as to expose the upper portions freely to the cleansing action of the rain, while the lower portions are shielded from the rain so as to keep them fairly dry, and preserve the insulation as much as possible during wet weather. The wires are attached to the insulators by being wound round them and firmly soldered together, so that if a breakage takes place at any point, the wire between the neighboring poles will not be dragged from its supports, but the broken ends will simply fall where the breakage takes place.

In places where there is danger of trees falling on the wires, as, for example, in some parts of America, insulators consisting of glass blocks with slits cut in them are largely employed, the wire being simply passed through the slits, leaving a good deal of slack; and if a tree then falls across the line, it usually bears the wire down with it, taking up the slack from the neighboring poles, but not breaking it, and it will therefore generally stick in the branches without being brought down to the ground, so that the circuit will not be entirely interrupted.

When telegraph wires have to be taken through towns they are usually, when only few in number, carried over the tops of the houses, to which they are attached by means of porcelain insulators fixed to iron supports. If, however, the wires are numerous, they are generally carried underground, a number of wires being drawn together into iron or earthenware pipes, provided with what are called flush

boxes, at intervals of every one hundred yards when the line is fairly straight, or at more frequent intervals if it winds to any considerable extent. These flush boxes are provided with closely-fitting covers, to prevent, as far as possible, the entrance of moisture. The post-office telegraph wires in London are almost invariably laid in this manner, the pipes employed being of cast-iron, usually four inches in diameter, except where only a few wires are likely to be required, when smaller pipes are used. A four-inch pipe will take as many as one hundred and twenty-eight wires of the kind employed in the post-office telegraph system. Each wire has, of course, to be insulated by means of a covering, which is usually of gutta-percha or India-rubber. Overland telegraph wires in tropical countries, such, for example, as Australia and India, are usually carried upon iron posts, as the wooden ones would soon be destroyed by the attacks of the white ants or other insects, unless protected by creosote or some similar preservative process, which, however, in this case would involve much heavier expense than the employment of iron posts.

The use of iron posts in countries where transport is difficult has the additional advantage that they are very much lighter than wooden ones, and also that they can be made in sections and put together at the place where they are to be erected.

A very convenient form of iron post, extensively employed in Australia, was designed by Oppenheimer of Manchester. Its base consists of a sort of inverted pyramid with moderately sharp cutting edges, and it is driven into the ground by the blows of a descending weight which slides on the pole, and by means of a tripod arrangement is drawn up to a moderate height and then allowed to fall upon the

base until the upper or flat portion of the base is level with the ground.

In selecting the wire for a telegraph line, the chief considerations by which the choice must be determined are—low electrical resistance and durability, and also, when the wires are suspended on poles, mechanical strength.

The first two conditions are best fulfilled by copper, but until recently it has been difficult to get copper wire with much mechanical strength, except at a very high cost, and for this reason iron wires are almost universally employed upon lines carried on poles, copper being used for underground lines. Copper wire is now, however, being produced which has a tensile strength almost equal to that of steel, and a very low electrical resistance, and that at a cost considerably less than used formerly to be paid for ordinary commercial copper wire. It is therefore very possible that copper wires may come into general use in the near future, for, in addition to the electrical resistance of copper being much lower than that of iron, it will stand exposure to the weather for a very much longer time.

Faults.—Preece and Sivewright, in their work on the telegraph, from which, by the kind permission of the authors and publishers, most of the illustrations of the present chapter have been taken, classify faults occurring upon telegraph lines under three heads—viz., disconnections, earths, and contacts; which they then subdivide into total, partial, and intermittent. A total disconnection may be caused by a tree falling across the wire and breaking it, or by the wire being broken by the weight of the snow which accumulates upon it in a snowstorm; while partial disconnection may be produced by means of badly-made joints or bad earth connections, or by some of the joints of the

instruments not being kept properly clean. Total disconnection is of course indicated by the absence of current in the line when the battery is put on, and a partial disconnection is shown by the strength of the current falling below its proper value. Earths are indicated by an increase in the strength of a current at the transmitting station, and its decrease or entire cessation at the other end. A complete, or, as it is called, a *dead* earth, is caused by a wire resting on damp earth, or coming into contact with a wire or other object connected with the earth. Partial earths are caused by defects in the insulators, or by the wire coming into contact with imperfect conductors, such as walls, posts, or trees, in connection with the earth.

Contacts are caused by one wire touching another, or by two wires being partially connected, either by means of an imperfect conductor falling across the wires, or by defects in the insulators allowing the current in one wire to leak into another. When a number of wires are carried on the same poles, a great deal of trouble would be caused by this cross leakage if special precautions were not taken to prevent it, and this would be especially noticeable in wet weather, when the deposition of moisture on the insulators greatly diminishes their insulating power. The effect of this cross leakage would be that the messages sent along one wire would be transmitted to stations on other lines, and interfere with the messages travelling along them.

In order to obviate this inconvenience, the base of each of the insulators is connected, by means of a short wire, to an earth wire carried down the pole into the ground; and as this path offers a much smaller resistance than that from one wire to another, whatever leakage occurs will all go to earth, and the effect of this leakage can be remedied

by increasing the battery power at the sending station. These earth wires also act as lightning conductors, and it is a matter of great importance that efficient means should be provided for the lightning to escape to earth when it strikes a post, instead of travelling along the wires, when it would destroy the instruments, and possibly some of the operators as well.

In addition to these earth wires attached to the poles, the instruments themselves are protected by means of special lightning protectors.

The lightning protectors employed on the post-office lines, and which are found to be extremely efficient, consist of two flat brass plates, with their opposite surfaces carefully tinned to prevent oxidation, and kept at a small distance apart by means of thin paraffined paper or mica.

One of these plates is connected to the line and the other to the earth, and it is found that when a lightning discharge strikes the wire, it will jump across the small distance and go to earth, in preference to going round the circuit. Intermittent faults are often caused by the action of the wind blowing the lines against different bodies, or by bodies being brought into contact with them at intervals, owing to expansion and contraction by heat.

In order to enable faults to be localized and remedied with despatch, the wires on overhead lines are carried at intervals into testing boxes, and if a fault is found, tests are applied at these in succession until the fault is shown to occur between two adjacent ones. In the underground lines the flush boxes serve the same purpose. When the fault is thus localized the section in which it occurs is cut out, the exact position of the fault ascertained, and the wire repaired. If the section forms part of a busy circuit, from

which a wire cannot easily be spared, a section is usually cut out from a less busy circuit and introduced into the former one until the repair has been effected.

In a properly organized system no serious interruption will take place, unless in consequence of an extensive series of breakdowns, such as sometimes occurs during an exceptionally heavy snowstorm, for the borrowed wire will always be taken from a circuit which, in addition to not having any very heavy traffic at the time, also possesses an alternative route.

The overland telegraph system, like most other important undertakings in this country, was inaugurated and developed by private enterprise, but in the year 1870 it was purchased by the Government and placed under the direct control of the Postmaster-General. One of the most cherished privileges of an Englishman is his right of grumbling at the Government and every undertaking under its direction; and in many cases there is very good reason for such grumbling, for the waste in many Government departments is simply scandalous; and red tape, moreover, has been one of the most formidable obstacles to the successful development of many a valuable scientific invention. If, however, the post-office telegraph system is to be judged by its results, as seems only fair, there will not, I think, be found much scope for legitimate fault-finding. In the year 1870, when it was bought by the Government at twenty years' purchase, the telegraph system was bringing in an income of about £550,000 a year, and this has now increased to over £2,000,000 annually, the number of messages transmitted having increased in the same time from 6,000,000 to 58,400,000.

Mr. Preece, from whose most interesting address to the

British Association at Bath these figures are taken, reminds us in another portion of his address how easily accidental errors may creep into telegraph messages without any fault on the part of the operator. He tells us, for example, that a lightning flash in America might cause an extra dot in Europe, causing *mine* to become *wine;* or an earthquake in Japan might cause the addition of a dash and turn *life* into *wife;* or again, a wild goose flying against a telegraph wire might drive it into contact with another wire and turn *sight* into *night.* And yet he says, as a matter of fact, in ninety-nine cases out of a hundred the telegraph operator delivers to the editor of a newspaper copy which is far more accurate than the first proofs submitted by the printer of his own leader. As an example of the enormous strain which is sometimes thrown upon and successfully borne by the post-office officials, Mr. Preece tells us that on the occasion of the introduction of Mr. Gladstone's Home Rule Bill, on the 8th of April, 1886, no less than 1,500,000 words were sent from the Central Telegraph Office in London.

If it were not for the telegraph it would be quite impossible to carry on the railway traffic of the country with its present combined celerity and safety. Most railways are now worked on the block system, according to which the line is broken up into short sections, and only one train is allowed on any section at the same time, the moment at which it enters upon any given section being signalled from one signal-box to the other, and no other train is allowed to enter until the signalman has telegraphed that the section is clear. At the more important junctions the system of electrical signals is supplemented by ingenious mechanical arrangements which make it impossible for the signalmen, through inadvertence, to make any com-

bination of signals which would lead to an accident; and, as Mr. Preece tells us in his address, "the signalman is able to survey the line all round and about him. By aid of his electrical signals he can talk by telephone or telegraph to his neighbors, or his station-master; he learns of the motion of the trains he is marshalling by the different sounds of electric bells; he controls his outdoor signals by the deflection of needles, or the movements of miniature semaphores; he learns the true working of his distant signals by their electrical repetition. Machinery governs and locks every motion he makes, so that he cannot make a mistake."

The increase in the safety of railway travelling is shown by the figures given on the same occasion by Mr. Preece, according to which, while in the five years ending with 1878 thirty-five people on the average were killed annually from causes beyond their own control—in the five years ending with 1887 the average had been reduced to sixteen, which means that only one person is killed in 35,000,000 railway journeys.

CHAPTER XI

SUBMARINE TELEGRAPHS

THE first attempts, as far as is known, at sending the electric current through submerged conductors were made by Sömmering, who about the year 1808 made some experiments of the kind in St. Petersburg for the purpose of exploding gunpowder at a distance; and in 1815 he repeated his experiments in Paris, by means of a conductor laid upon the bottom of the Seine.

After the invention of his electro-chemical telegraph, described in Chapter IX., Sömmering proposed that Cronstadt and St. Petersburg should be joined by means of a submarine telegraph line, but the project was never carried out.

Ronalds also pointed out the possibility of submarine telegraph cables a few years later; but the first experiments in which telegraphic signals were actually transmitted under water appear to have been made in 1839 by an Irishman, Dr. O'Shaughnessy, who employed conductors made of wire, covered over with pitch and tarred hemp, and succeeded without any difficulty in transmitting signals.

In 1837 Wheatstone proposed laying a cable from Dover to Calais, to be worked by the needle apparatus invented by Cooke and himself, and described in Chapter X., and in the following year a committee of the House of Commons

was appointed to inquire into the subject. Some preliminary experiments, however, which were made at the Observatory of Brussels were not altogether satisfactory, and the project was dropped.

Wheatstone made some further experiments in Swansea Bay in 1844, and in the following year, when gutta-percha was first introduced into this country, he at once perceived its value as an insulator for submarine telegraph wires.

Morse also turned his attention to the subject, and made some experiments with an insulated submerged wire at New York in 1842, and in the following year he submitted to the American Government a project for establishing telegraphic communication between America and Europe.

In 1845 Cornell laid down a cable twelve miles long in the Hudson River to establish communication between Fort Lee and the city of New York. This cable was composed of two copper wires separately wound over with cotton, insulated by means of India-rubber, and inclosed together in a leaden tube. It was in use for some months, after which it was cut through by the ice.

West, in the year 1846, applied to the English and French Governments for permission to lay down a cable between Dover and Calais, and carried out some preliminary experiments in Portsmouth Harbor in the presence of a large number of spectators.

In 1848 Armstrong made some further experiments of the same kind in the Hudson River, and suggested, in an article published in one of the New York papers, that a similar cable should be laid across the Atlantic.

Werner Siemens in the same year carried out some experiments on the explosion of torpedoes by means of submerged electric cables in Kiel Harbor; and Walker in 1849

constructed a cable, consisting of copper wire, covered with gutta-percha, about two miles in length, and laid it out into the sea from Folkestone. This cable was connected with the overland line from London to Folkestone, and messages were sent by it between London and Mr. Walker's yacht, two miles from the shore.

In the meantime Brett, in 1847, had obtained a concession from the French Government for laying a cable between England and France, and in 1849 a company was formed for carrying out the project. A cable twenty-five nautical miles in length was manufactured. It was made of copper wire covered with gutta-percha, and was constructed in separate lengths of one hundred yards, which were joined by twisting the ends of the copper wire together and binding them over with gutta-percha which had been softened by heating.

This cable was laid in August, 1850, simultaneously from Cape Gris-nez and Dover, the cable being simply passed overboard from drums on which it was wound; and leaden weights of ten or twelve pounds, to act as sinkers, were fixed at intervals of about one hundred yards. When, however, the two ends were joined together it was found that the cable had been broken, and although attempts were made to take it up and repair it, they were unsuccessful, as the cable was not strong enough to lift up the leaden weights used as sinkers.

The original concession obtained from the French Government expired in 1850, but a further extension of a year was obtained. The failure of the previous attempts, however, had made capitalists distrustful of the project, and if it had not been for Mr. Crampton, who found half the capital required himself, the project would have fallen

through. As it was, however, a cable was constructed by Messrs. Newall & Co.

It was formed of four copper wires, each covered with a double layer of gutta-percha. These were twisted together, and the intervals filled up with tarred hemp, after which it was wound over with tarred cord, and the whole covered with a set of ten thick iron wires wound round it in order to protect it from injury. The cable was laid down from Sangate, but the weather was very unfavorable, so that the vessel laying it was unable to keep her course, and when the whole of the cable was paid out, she was still about a mile from the French shore. Temporary communication, however, was established by means of three wires simply covered over and bound together, and this extemporized cable was afterward replaced by means of a length of cable similar to the rest, and in November, 1851, the cable was actually opened to the public, and since then, though it has frequently been repaired, it has never been entirely renewed.

The success of this cable restored the confidence of capitalists, and an attempt was soon made to lay a cable between England and Ireland. The first of these was laid down from Holyhead to Howth, the cable being very similar to the Dover one, but the insulation was bad, so that when it was completed it was found that signals could not be transmitted, and attempts were made to pick it up and mend it; they were not, however, successful. Two other attempts were rendered unsuccessful, by the vessel laying the cable being carried out of her course by currents; but in the year 1853, a large cable containing several conducting wires was laid between Portpatrick and Donaghadee.

The possibility of successful submarine cables having now been completely demonstrated, there was no difficulty

in obtaining capital, and numerous short cables were laid down, connecting different European countries.

In the meantime the success of the second attempt to lay a cable between Dover and Calais had resuscitated the idea of establishing electrical communication between Europe and America.

In the year 1851, Tebbets, an American, and Gisborne, an English engineer, obtained a series of concessions from the Government of Newfoundland, and formed a company under the title of the Electric Telegraph Company of Newfoundland. This company laid down twelve miles of cable between Cape Breton and Nova Scotia, but as it was unable to carry out all that it had undertaken, it was shortly afterward dissolved, and the concessions transferred to the Telegraphic Company of New York, Newfoundland, and London, founded by Cyrus W. Field, who, in 1854, obtained a further concession, giving to the company the sole right of carrying cables to Newfoundland for a period of fifty years.

A cable eighty-five miles long was then laid between Cape Breton and Newfoundland, and, in 1856, Field came over to England with a view of raising the capital for laying a cable between Ireland and Newfoundland. Here he associated himself with Brett, Whitehouse, and Charles Bright, who founded an English Company, which amalgamated with the American one, under the title of the Atlantic Telegraph Company.

The capital of this company was provided by three hundred and forty-five contributors, who subscribed a thousand pounds each. Among these contributors the name of Mr. John Pender, now Sir John Pender, K.C.M.G., must be specially mentioned, as from this time forth he practically took the lead in the development of submarine telegraphy.

Before the new cable was constructed, a number of experiments were made by Mr. Whitehouse, to determine the manner in which the rate of transmission of signals depended on the length of the cable; and he found that the time required for the transmission of a signal increased at a somewhat more rapid rate than the length of the line, but not in proportion to the square of the length, as appeared to be indicated by the theory of the subject, which, however, was at that time quite in its infancy.

In the course of these experiments, Whitehouse made the very important discovery that the rate of signalling could be increased in the ratio of about three to one, by making the currents flow through the cable in opposite directions alternately, instead of always in the same direction.

As the Atlantic cable would be nearly two thousand miles in length, it was thought advisable, before incurring the expense of having it constructed and laid down, to obtain definite experimental evidence of the possibility of transmitting signals over so long a line.

Accordingly, in October, 1856, Whitehouse and Bright connected up a series of existing submarine cables with the subterranean line between London and Manchester, and in this way made up a circuit of about two thousand miles in length, and it was found that from about 210 to 240 distinct signals could be sent over this circuit in a minute, and therefore the commercial practicability of using the line, if it could be constructed and laid successfully, was conclusively demonstrated.

The core of the cable was made by the Guttapercha Company, of Silvertown, and consisted of seven copper wires, covered with three layers of gutta-percha. The core was covered with hemp soaked in a composition of Norwegian

tar, pitch, linseed oil, and wax, and was protected outside by means of eighteen ropes, each formed of seven iron wires. The covering was manufactured and laid on by Messrs. Glass, Elliot & Co., and Messrs. Newall & Co.

The shore ends of the cables were protected by a much heavier armor, consisting of twelve thick iron wires twisted round the cable in a helical form, as was done with the wire ropes used in the deep-sea portions.

Owing to the absence of previous experiments on the requirements of such a cable, and also to the haste with which its manufacture was carried out, the cable was unfortunately exceedingly defective, and Mr. Whitehouse strongly advised its rejection. It was, however, decided to lay it down, and it was embarked on board two vessels—the "Niagara," a vessel of five thousand tons, belonging to the United States Navy, and the "Agamemnon," an English warship, of three thousand two hundred tons.

It was decided to lay the cable from Valentia, in Ireland, to Newfoundland, as the ocean bottom between these two places had been explored by Captain Maury, of the United States Navy, and found to consist of a gently undulating plateau, covered with fine mud, usually known by the name of Atlantic ooze, forming a very suitable bed for the cable.

The shore end of the cable was laid down from Valentia by means of two smaller vessels, and was safely effected on the 6th of August, 1857. On the following day the shore end was joined with the portion on board the "Niagara," and the paying out of the cable went on successfully until the 11th of August, when, after a length of 334 nautical miles had been laid down, the cable broke, owing to an accident with the paying-out machinery, in a depth of over 2,000 fathoms of water. Owing to this accident the vessels

returned to Plymouth, and the cables were landed at Keyham, and stored in dry tanks. The most defective portions were there replaced by new ones, and an additional length of 750 miles was manufactured by Messrs. Glass, Elliot & Co. The paying-out machinery was also very greatly improved.

This time it was decided to begin laying the cable in mid-ocean by the two vessels simultaneously, the "Agamemnon" proceeding toward Valentia, and the "Niagara" toward Newfoundland. The cable was broken several times in laying, and about 640 miles of it were lost, but at last every difficulty was overcome, and communication established on the 5th of August, 1858.

It was found, however, that the signals transmitted by the cable gradually became less distinct, and on the 1st of September they ceased to be intelligible. During the time that communication was established the English Government had made use of the cable to send a message to Canada, countermanding the departure of two regiments which were about to return to England; and, as they would have had to be sent back again, a considerable expense was thereby saved to the country. This was a fortunate circumstance, as it illustrated in a very striking manner the advantage of establishing telegraphic communication between England and America, and had an important effect in encouraging further attempts.

Several attempts were made in 1860 to pick up this cable, but they were all unsuccessful. The Atlantic Telegraph Company did not, however, for a moment abandon their hopes of success, and two vessels were sent out to explore the ocean bed between Ireland and Newfoundland. They found that several portions of the bottom where the

old cable had been laid were of a rocky character, very likely to damage the cable, and a new course was therefore marked out for the next attempt, about twenty-seven miles to the south of the former one, the positions selected for the shore ends being the Bay of Heart's Content in Newfoundland, and Foilhommerum, close to Valentia, in Ireland. A new cable was manufactured by the Guttapercha Company, the core having been designed by Messrs. Glass, Elliot & Co. In its general character it was similar to the former one, but the construction was very greatly improved.

As the results of the 1857 expedition had shown the inconvenience of employing two vessels to lay the cable simultaneously, the "Great Eastern," of 22,500 tons, was chartered to carry the entire cable, which was coiled on board in three immense iron tanks, and Captain, now Sir James, Anderson was appointed to command the vessel, Mr. Canning being engaged as engineer, and Professor, now Sir William, Thomson and Mr. F. Varley as electricians. The Irish shore end, which had been made by Henley of Woolwich, was laid down by a smaller vessel on the 26th of July, 1865, and was joined to the main portion on board the "Great Eastern" on the following day, when the process of paying out the cable was at once begun.

On the 24th of July, after 84 miles of cable had been laid down, a fault was discovered in the portion which had been submerged, and ten and a half miles of cable had to be wound in before the fault was got on board, when it was found to be due to a small piece of iron which had penetrated the insulating covering, and made connection between the copper core and the water.

A second fault occurred when 716 miles of cable had been laid down, and this also was successfully repaired. A third fault was observed on the 2d of August, after 1,186 miles of cable had been paid out, and the cable had to be wound in from a depth of about two thousand fathoms. After about a mile of cable had been recovered an accident occurred to the picking-up machinery, and it became necessary to stop the ship; it was therefore temporarily at the mercy of the waves, and the cable, unable to bear the strain to which it was subjected, parted and was lost overboard.

Several attempts were made, by means of grapnels, to pick it up; but although the engineers succeeded in getting hold of the cable, the tackle was not strong enough, and gave way in every case before it was brought to the surface. Ultimately, the attempts had to be abandoned, as all the picking-up tackle was exhausted. This disaster ruined the Atlantic Company financially, and there appeared very little prospect of raising the capital for another attempt; for many of the original contributors were dead, while others had begun to despair of the ultimate success of the project as a commercial enterprise, and preferred the certainty of losing what they had already put into it, to the risk of investing further capital in what scarcely seemed more than a forlorn hope.

This, however, was fortunately not the opinion of Mr. John Pender and a few others who shared his faith in the ultimate success of the enterprise; and the Anglo-American Company was formed, with a capital of £600,000. to carry on the work of the defunct Atlantic Company.

The first object of the new company was to lay down a new and improved cable; and the second, to endeavor to

repair and complete the former one. Negotiations for the manufacture of a new cable were therefore opened with Messrs. Glass, Elliot & Co., and with the Guttapercha Company; but the latter found it was giving up much of its ordinary business in order to carry out this one attempt, which, if it were unsuccessful, might involve them in ruin, and they refused to proceed with the work unless they received a guarantee amounting to a quarter of a million.

Delay at this moment would have been fatal to the project, and would have involved the loss of all the capital, amounting to nearly two millions, which had already been expended; but when Mr. Pender was informed by the company of their demand, he simply asked whether his personal guarantee would suffice; and on being told that it would, he at once gave it, and the work was put in hand forthwith.

Another cable was made very similar to the former one, except that the iron wire, used for armoring the cable, was galvanized to protect it from the disintegrating action of the water.

New paying-out and picking-up machinery of a greatly improved type, and driven by an engine of seventy horse-power, was placed on board the "Great Eastern"; and the "Medway" and "Albany," which were to assist the "Great Eastern," were provided with similar machinery. Two vessels of the British Navy, the "Terrible" and the "Raccoon," were told off to accompany the expedition, and render any additional assistance that might be required. The shore-end of the cable was laid down in the Bay of Foilhommerum on the 7th of July, 1866, and on the 13th the junction with the cable stored on board the "Great Eastern" was effected, and the latter vessel started on its

voyage to Newfoundland, where it arrived on the 27th of July, after having been successful in laying the 1,852 miles of cable without any mishap. The cable was laid along the line previously marked out, which was, as already stated, twenty-seven miles to the south of the old cable.

On the 9th of August the "Great Eastern," accompanied by the "Medway," put to sea to endeavor to find and pick up the old cable, and three days later they met the "Terrible" and the "Albany," which had been despatched eighteen days earlier to endeavor, in the first place, to find, by means of astronomical observations, the place where the cable had been abandoned; and, secondly, to begin dragging for it. When the "Great Eastern" arrived, the "Albany" had already grappled the cable, lifted it a certain distance, and supported it by attaching it to a buoy; but the chain had broken, so that the cable had fallen back to the bottom, carrying with it about two thousand fathoms of chain. Canning's plan for picking up the cable was that the "Great Eastern," the "Terrible," and the "Albany" should drag for it simultaneously, and when they had grappled it, and lifted it to a certain height, the "Medway" was to cut it on the westerly side, so as to allow the Valentia end to be picked up. Several times the vessel succeeded in getting hold of the cable, and once it was brought to the surface, but it slipped out of the grapnel as attempts were being made to attach a chain to it. At last, however, on the 13th of August, the cable was grappled and lifted to within 800 fathoms of the surface, when the chain to which the grapnel was attached was fastened to a buoy. The "Great Eastern" then began to drag three miles to the west of the buoy, and the "Medway" two miles to the west of the "Great Eastern," and both vessels succeeded in get-

ting hold of the cable, the position of which was then as shown in Fig. 39. The "Medway" then cut the cable by means of a cutting grapnel at a depth of 300 fathoms.

The part grappled by the "Great Eastern" was then at a depth of 800 fathoms, the process of lifting it having been stopped at that depth, as the strain upon the grapnel had risen to over twenty tons, and it was feared that any further increase would cause it to give way. When, however, the cable had been cut by the "Medway," the strain diminished to ten or eleven tons, and the "Great Eastern" recommenced the work of picking up. It was got on board and connected with the electrical instruments on the 2d of

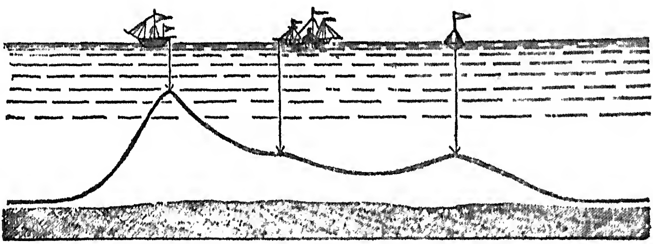


FIG. 39.

September, and the happy result was immediately signalled to Valentia. The extra cable which had been provided for repairing the old one was then joined to the latter, and the "Great Eastern" began laying it down in the direction of Newfoundland, arriving safely at the Bay of Heart's Content on the 8th of September, when it was attached to the shore end, which the "Medway" then proceeded to lay down; and the same evening communication was established through it between Newfoundland and Valentia. The total length of cable laid down amounted to 1,896 miles.

During this second expedition the vessel was com-

manded, as before, by Captain Anderson, and Mr. Canning directed the operations of laying and repairing, while Professor Thomson and Mr. Willoughby Smith were in charge of the electrical tests on board, and Mr. Varley remained at Valentia to superintend the testing operations there. Since the successful laying of the Atlantic cable in 1866, new cables have been laid down in gradually increasing numbers almost every year, until at present they form a complete network, connecting, in conjunction with the overland telegraphs, all the more important places in the civilized world. The experience thus gained has of course led to many improvements in the construction of the cables, in the methods of laying them down, and picking them up for repairs, and in the apparatus used for transmitting and recording signals.

Cables are often made with several separate conductors instead of only one, the different terminals being connected to different lines on shore; but whether one conductor or several are employed, each of them is now invariably made, not of a single copper wire, but of several wires, usually three or seven, as this is found to entirely obviate the difficulty arising from the brittleness of solid copper wire, which caused a great deal of trouble in the earlier cables, as the solid wire was found to break after being bent a few times.

The covering of hemp or jute, which is spun round the insulated core to serve as a pad or protection against the pressure of the iron wires forming the armor of the cable, is usually known as the "*serving*"; and when the cable is made up of several separate conductors, they are usually arranged in a circle round a central core of hemp or jute known as the "*worming*."

In the earlier cables both the *serving* and the *worming* were saturated with tar, in order to diminish their liability to decay in the water; but Mr. Willoughby Smith found that tar temporarily mended small defects in the insulation, and might therefore prevent any injury to the core from being discovered in time to allow of its being repaired before the cable was laid down; while it was not a sufficiently good insulator to mend the fault permanently, and therefore it is now no longer used, the hemp being tanned instead. In shallow waters submarine telegraph cables are very liable to injury, either from anchors dragging over them, or from their being chafed against a rocky bottom; or again from the attacks of various submarine animals, such as the Teredos, which will bore into a cable as it would into timber, if any portion of the armor is removed by injury. It appears, however, to confine itself to the exposed portions, and will not bore into those portions of the hemp which lie underneath the iron wires. There is also a case on record of a swordfish having left its weapon buried in the insulating coating of a telegraph cable.

When any such fault occurs its presence can be detected, and its position ascertained, by electrical tests made, either at one end of the line, or at both ends simultaneously, with the aid of adjustable resistance which is inserted into the circuit between the end of the cable and the earth connection.

This adjustable resistance consists of a series of coils, the resistances of which are all known multiples of a definite unit, usually the Legal Ohm. The resistance per mile of the cable is known from tests made before it is laid down, and when a fault occurs the electrical tests enable the resistance of the cable between the fault and either end to be determined, and therefore the distance along the cable at which

the fault occurs is obtained by simply dividing the total observed resistance by the resistance of a mile of the cable.

The first successfully-laid Dover and Calais cable, and the other short cables which were laid shortly afterward, were worked by means of needle instruments, or other ordinary telegraph apparatus then in use on overland lines. None of these, however, was sufficiently delicate to give good results over a great length of cable, and they were therefore very soon displaced by the mirror galvanometer. It has already been mentioned that this instrument was originally devised by Gauss and Weber, and employed on their telegraph line at Gottingen. It was subsequently very much improved by Sir William Thomson, and one of the instruments made by him was employed at Valentia during the few weeks that communication was possible through the cable of 1858.

Thomson's astatic reflecting galvanometer, now employed for submarine cable work, consists of a pair of magnets connected rigidly together in such a way that when suspended by a silk fibre they will hang horizontally one above the other with similar poles pointing in opposite directions. The two magnets are of as nearly equal strength as it is possible to make them, so that when placed in a magnetic field the directive force acting on them is very much weaker than it would be upon a single magnet only. The magnetic field is usually produced by means of a small magnet bent in a vertical plane in the form of a circular arc, and made to slide upon an upright rod attached to the case of the instrument.

This is more convenient than using the earth's magnetic field, because, by means of the adjustable magnet, the suspended magnets can be made to turn in any desired direc-

tion. These suspended magnets are exceedingly small and light; and each of them is attached to the back of a small mirror formed of silvered microscope glass. A very large number of turns of exceedingly fine silk-covered copper wire are then wound round the pair of suspended magnets in a coil having the shape and position of a vertical figure of 8. The result of this is, that whatever the direction of the current through the coil, the effect of the portions surrounding each of the two suspended magnets is to turn them both in the same direction.

The resistance of a galvanometer of this kind is very high, generally from seven thousand Ohms upward, but this does not produce any sensible diminution in the strength of the current, which by Ohm's law is equal to the electromotive force divided by the total resistance, because the resistance of the cable is so great that the galvanometer resistance does not increase it by any perceptible proportion of the whole.

The object of using exceedingly fine wire is to enable a very large number of turns to be wound in very close proximity to the suspended magnet, in order to magnify as much as possible the effect of the weak current passing through the cable.

In reading a message by means of the mirror galvanometer, it is placed close to the observer; and opposite to it, at a considerable distance, is placed a horizontal scale, at the centre of which is a small vertical slit. A lamp is placed beyond this slit, and its rays, concentrated by means of a lens, are allowed to fall upon the mirror, and reflected back upon the scale. The observer watches the motion of the spot of light upon the scale, and the reader will easily see that a very small motion of the mirror will be sufficient

to give a perfectly perceptible motion to the spot of light. The dots and dashes of the Morse code are indicated by motions to the right and left respectively of the centre of the scale.

It is exceedingly fatiguing to the eye to watch the motion of the spot of light in the mirror galvanometer for any length of time, and although the instrument is still largely employed for making electrical tests, it has been to a great extent superseded for signalling purposes by the "Siphon" recorder, a most beautiful and ingenious instrument, which is also the invention of Sir William Thomson. The construction of this instrument is far too complicated for me to tax my readers' patience by describing it in detail, but its general principle is very easily understood.

A flat coil of very thin wire, in circuit with the line, is suspended by means of silk fibres between the poles of a powerful electro-magnet, in such a way that when no current is passing through it, it hangs with its plane vertical and passing through the line joining the poles of the electro-magnet. When a current is sent through the suspended coil the latter behaves like a magnet, just as in Ampère's experiments, and tries to set itself with its plane perpendicular to the line joining the poles of the electro-magnet. The suspended coil is made to communicate its motions by means of fine silk fibres to a very fine glass siphon, one end of which dips into an insulated metallic vessel containing ink, while the other extremity rests, when no current is passing, just over the centre of a paper ribbon which can be carried underneath it by means of clockwork. When the instrument is to be used, the vessel of ink is connected with an electrically charged conductor, the effect of which is to drive the ink out of the siphon in small drops. The

clockwork is at the same time set in motion, the result being to draw a fine dotted line along the centre of the ribbon.

When currents are sent through the line the point of the siphon moves alternately above and below the line, drawing a wavy instead of a straight line, and this wavy line gives a permanent record of the message, the motion of the siphon above the central line corresponding to the dots of the Morse code, and its motion in the other direction corresponding to the dashes. It has already been mentioned that Whitehouse found in his experiments, preliminary to the first attempt to lay an Atlantic cable, that the rapidity of signalling could be greatly increased by sending currents alternately in opposite directions through the line. This he himself attempted to effect by the use of a small magneto machine, but a more satisfactory method is to alternately connect the copper and zinc poles of the battery at the transmitting station with the cable, the end not in connection with the cable being at the same moment put to earth. In order to obtain the best effects, the duration of the different currents in opposite directions should bear definite ratios to one another, depending of course on the succession of signals to be sent. It is very difficult to do this satisfactorily with any form of key operated by hand, but it is done most effectively by means of the automatic curb transmitter, an instrument devised by Sir William Thomson for use with the siphon recorder, and which automatically makes, breaks, and reverses the contacts as required, under the guidance of a strip of punched paper similar to that employed with the Wheatstone automatic transmitter, which was described in the last chapter.

CHAPTER XII

THE TELEPHONE

THE first recorded attempt to transmit speech by electricity was made by Philipp Reis, a German schoolmaster, who began his researches in the year 1860. His first transmitter was formed out of the bung of a beer-barrel, hollowed out, and having one end closed with the skin

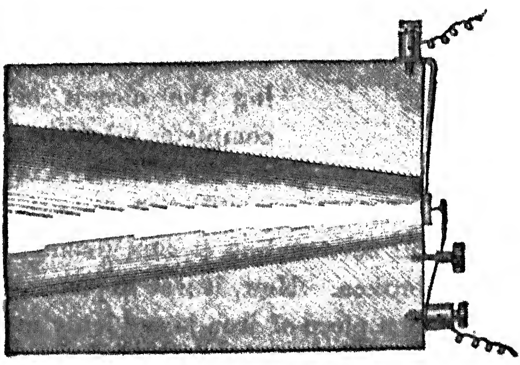


FIG. 40.

of a German sausage to serve as a membrane. A somewhat less primitive form of the instrument is shown in Fig. 40. It consisted of a cube of wood, hollowed out in a conical form, and having the smaller end of this hollow closed with a very fine stretched membrane. A narrow springy strip of platinum foil was attached to the upper binding screw, as

shown in the diagram, while its lower end rested against the centre of the membrane. A second platinum strip, provided with a contact point, was attached to the lower binding screw, and, by means of the adjusting screw shown in the illustration, was made to just touch the lower end of the first platinum strip.

The two binding screws were placed in circuit with the battery and with the line through which messages were to be sent. Reis's original receiver, shown in Fig. 41, consisted simply of a violin, upon the bridge of which was stuck upright a knitting-needle, surrounded by a coil of silk-covered copper wire. If a musical note was sounded opposite the larger end of the hollow of the transmitter, the membrane was thrown into vibration, making and breaking the circuit once at each complete vibration. As often as the circuit was completed the knitting-needle was magnetized by the coil surrounding it, and demagnetized when the current was broken. Now, it was explained in a former chapter that when a piece of iron is suddenly magnetized or demagnetized a slight sound is heard, and as the number of magnetizations and demagnetizations in a second was equal to the number of vibrations corresponding to the note sounded at the transmitter, the result was that the note was reproduced. Reis attempted to use his instrument for transmitting words spoken into the transmitter, but he does not seem to have been able to do more than occasionally reproduce a single syllable or short word, and that very indistinctly.

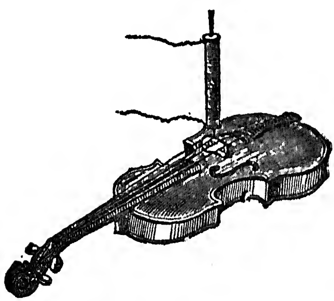


FIG. 41.

We now know that the reason of this was that the sounds emitted by the human voice are of much too complicated a nature to be reproduced by any apparatus which simply makes and breaks the circuit, and although Professor S. P. Thompson has been more or less successful in transmitting articulate sounds by means of instruments of similar construction to those of Reis, it has only been by very carefully adjusting the contact-breaking spring, and speaking to it very softly, so as only to vary the pressure

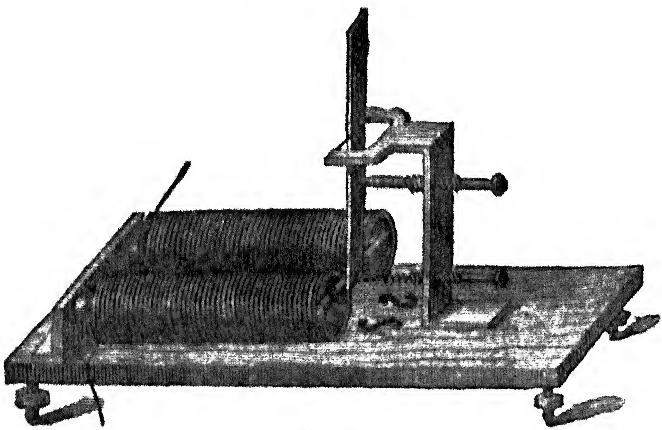


FIG. 42.

between the two platinum surfaces instead of actually breaking the contact. Reis made a great number of other transmitters of an imperfect form, one of which is shown in Fig. 42. It consisted of a double electro-magnet about six inches in length, laid horizontally upon a wooden sounding-board. In front of the poles of the electro-magnet was placed an iron rod of elliptical section, attached to a wooden lath supported on a cross wire, and capable of having its position regulated by means of the upper adjusting screw, and a tension spring attached, as shown, to the lower screw in the illustration.

It is curious that though Reis provided his transmitters with elaborate mouthpieces, he never attempted anything of the kind for the receiver, although subsequent experiments have shown that it is a much more important feature in the latter case than in the former.

The first speaking telephone was the invention of Alexander Graham Bell, a Scotchman who had settled in the United States and become a naturalized American citizen.

The first telephones constructed by Bell were not speaking ones, and one of these earlier forms is shown in Fig. 43. The same instrument served either for transmitting or re-

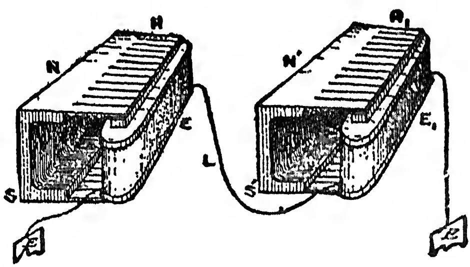


FIG. 43.

ceiving the message, and consisted of a pair of harps formed of steel rods attached to the poles of a permanent magnet, NS, and having their free ends respectively above and below the soft iron core of an electro-magnet, E.

Two such instruments are shown in the diagram connected up ready for use; one end of the coil of each electro-magnet is earth-connected, and the other two ends are connected with each other through the line.

If one of the bars of the harp H is thrown into vibration mechanically, or by singing to it or playing a musical note in its neighborhood, it will send an undulatory current, of a period corresponding to that of the note, through the line,

and this will set in vibration the corresponding rod of the harp H—that is to say, the rod giving the same note as that which was sounded at the transmitting station; the reason that one of the rods will respond to a note sounded near it is that its period of vibration is equal to the period of the note, so that the successive impulses caused by the waves striking the rod all tend to increase the vibration instead of counteracting each other's effects. A familiar example of exactly the same phenomenon is given by the well-known fact that if the sounding-board of a piano is lifted and a certain note sung above the strings, it will be taken up by the string giving the same note. The study of the notes required to produce the different vowel sounds shows that if a piano were made with a sufficient number of strings to each octave, or a harp such as that used by Bell with a sufficient number of rods, vowel signs could be perfectly reproduced by setting them in vibration one after another. Bell pursued this idea for some time, as he thought it might give a convenient means of sending a number of messages simultaneously along the same line. This was to be effected by a pair of notes being selected for each pair of instruments, to give signals corresponding to dots and dashes respectively, a different pair of notes being used for each such pair of instruments.

The clerk at the transmitting station would simply have, by means of a suitable key, to set his pair of rods in vibration in the proper manner to transmit a message. At each receiving station a number of the rods actuated by the sending instruments would be vibrating together, but it was supposed that each clerk would be able to pick out the two notes which it was his business to attend to, and to train his ears so as to distinguish these while neglecting the

others. The plan might possibly be a success if telegraph clerks invariably possessed accurately trained musical ears, but unfortunately comparatively few persons possess the power of training their ears to the extent which would be necessary.

After a long series of experiments, the transmitter shown in Fig. 44, and the receiver shown in Fig. 45, were constructed, and these are of special interest as being the first pair of instruments that could really be said to form a speaking telephone. They were exhibited in Philadelphia in 1876, and at the meeting of the British Association in the same year, Sir William Thomson excited a widespread interest by exhibiting this receiver to the meeting at Glasgow, and giving an account of the results obtained by Mr. Bell in the same year.

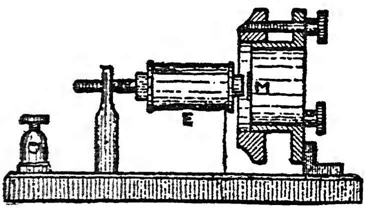


FIG. 44.

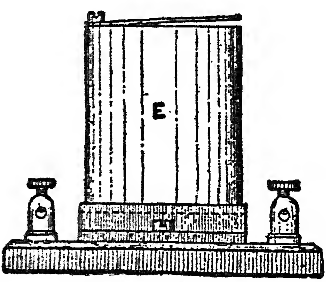


FIG. 45.

The first public exhibition of the speaking telephone in England was given by Mr. Preece at the Plymouth meeting of the British Association in 1877, when the Glasgow receiver had been abandoned, and the transmitter modified into a form not differing greatly from that shown in Fig. 46, which represents the Bell receiver now in use, and which was used for some time both as receiver and transmitter. It consists of a case made of wood or ebonite, the latter being now almost universally employed, containing a per-

manent steel magnet, *a*, opposite which is a vibrating plate, *pp*, made of thin steel.

The distance between the magnet and the plate can be adjusted by means of the screw, *d*. On the N end of the magnet is placed a small boxwood reel, *bb*, wound with silk-covered copper wire, the ends of which are connected by means of the terminals, *hh*, with the line LS. The mouth-piece, *VV*, is fastened by means of two screws, *ff*, to the projecting flange *UU*, of the case, and holds the vibrating diaphragm in position. This diaphragm is made of a ferrotype plate such as that used by photographers, which gives

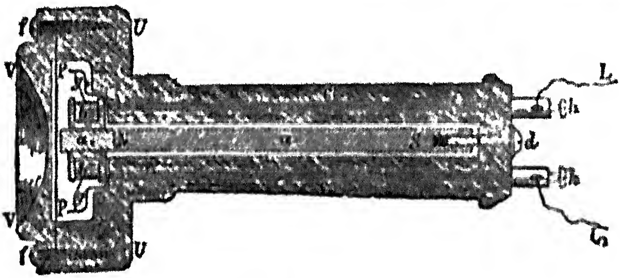


FIG. 46.

a much clearer intonation than the membranes employed in the earlier instruments. The principle of these instruments is similar to that of the harp telephone first made by Bell, except that the harp, which can only produce a limited number of definite notes, is replaced by the steel diaphragm, which reproduces with more or less clearness all the notes which go to make up the human voice.

As in the former instrument, no battery is required, the undulatory current being produced by the vibrations of the diaphragm spoken to, and reproducing the sound in the receiving instrument, by setting up vibrations in its diaphragm, synchronous with those of the first.

The next advance in telephony was made by Edison's invention of the carbon transmitter. This instrument, which is shown in Fig. 47, was based on the discovery, made by Du Moncel in 1866, that an increase of pressure between two conductors in contact causes a diminution in the electrical resistance of the circuit of which they form a part. E is an ebonite mouthpiece, D a vibrating plate, and I a disk of prepared carbon about the size of a shilling, the distance of which from the vibrating plate can be adjusted by means of the screw, V. A small platinum plate, B, carrying a rounded ivory button, *b*, is fixed to the upper

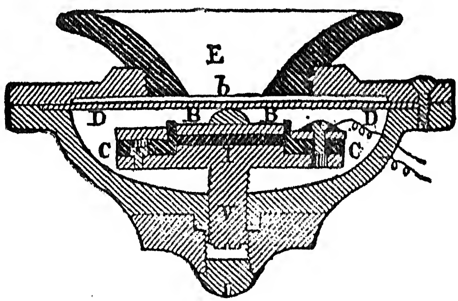


FIG. 47.

surface of the carbon disk. When the membrane is set in vibration by speaking to it, the vibrations are communicated to the carbon by means of the small platinum plate; and the variations of pressure produced in this way cause a variation in the electrical resistance of the contact, and therefore set up a series of undulations in a battery current made to traverse the circuit. In practice it is found better, when using the carbon transmitter, not to place the receiver in circuit with the battery and transmitter, but to allow the undulatory current from the latter to traverse the primary wire of a small induction coil, and to place the receiver in circuit with the secondary wire of the same coil, in which

undulatory currents are produced by the inductive action of the original current.

In the same year that Edison devised the carbon transmitter, Mr. Hughes read a paper before the Royal Society in which he described an instrument of a very similar character, to which he gave the name of the "microphone." A simple and efficient form of this instrument is shown in Fig. 48, and consists of a pencil of gas carbon (viz., the residue left in a gas retort when the gas has been expelled

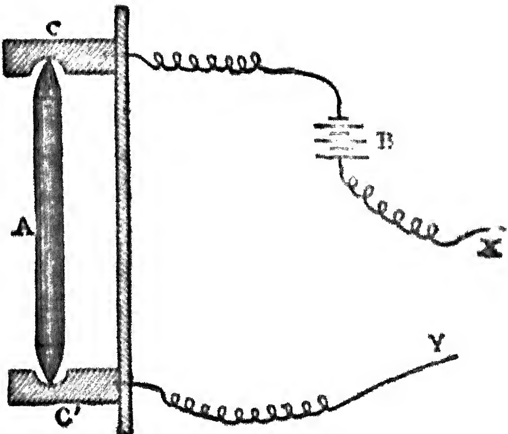


FIG. 48.

from the coal) pointed at each end and resting in cups, CC, of a similar material. When this instrument is connected through a battery, B, with a circuit, XY, containing a telephone, it is found to act as a very powerful telephone transmitter, and the slightest touch against the pencil will produce a grinding noise in the telephone. If the instrument is allowed to rest on a small wooden match-box in which a fly is walking, the noise produced by its motions can be distinctly heard in a telephone in circuit with the microphone.

A large number of carbon transmitters of various kinds have been devised by different inventors, all of them modifications, not of Edison's transmitter, but of Hughes's microphone. Of these it will be sufficient to describe the Blake transmitter, which is the one universally used in connection with the telephone exchanges in Great Britain. It consists of a small wooden frame, H, Fig. 49, hollowed out in the centre so as to form a mouthpiece, *a*, and carrying on its reverse side an iron ring, *rr*, Fig. 50, to which are screwed two pieces, *bb*, opposite to each other. These are connected by the conducting rail *c*, which is kept in position by means of the brass plate *m* and the screw *n*. The iron diaphragm *e* is placed immediately behind the funnel-shaped mouthpiece *a*. Between the diaphragm and the vertical rail *c*, the upper part of which is bent at right angles, there is an interval of about three-quarters of an inch.

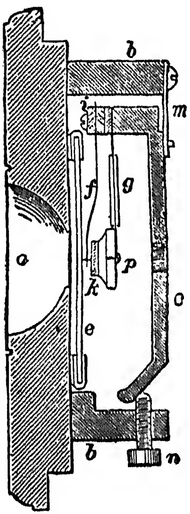
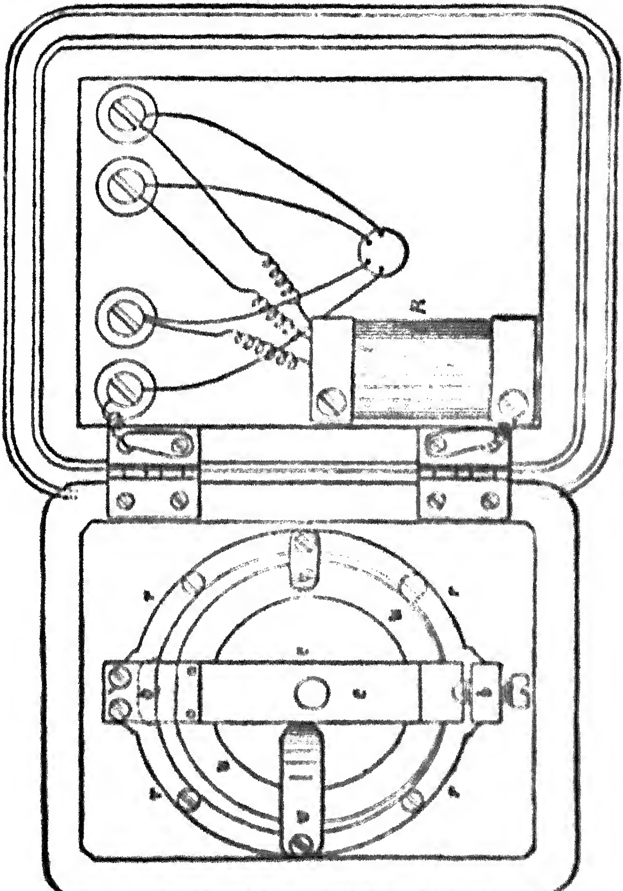


FIG. 49.

A strip of insulating material, *i*, carries a thin flexible steel spring, *f*, the lower end of which terminates in a small platinum button pressing on one side against the diaphragm, and on the other against a small carbon disk, *k*, fastened to a small brass plate, *p*. The latter is fastened to the lower end of a flat spring, *g*, the upper end of which is fixed, as shown, to the shorter arm of *c*. The spring *g* is coated with gum, and is only in electrical connection with the spring *f* by means of the platinum contact. The diaphragm *e* is contained in the India-rubber ring *u*, Fig. 50, and is kept in position

by the springs *vv'* which are screwed to the ring *r*. The frame H forms the door of a small case containing the induction coil, R. The current passes from one pole of the battery, through the primary coil, over the ring *r*, the



upper piece *b*, the brass plate *m*, the upper arm of the rail *c*, the spring *g*, the brass plate *p*, the carbon disk *k*, and the platinum contact of the spring *f*, back to the other pole of the battery, the secondary coil being placed, as before

explained, in circuit with the line and receiver. When the diaphragm *e* is thrown into vibration, the vibrations are transferred to the spring *f*, causing a variation in the pressure between the platinum contact and the carbon disk *k*.

According to Mr. Preece, from whose book on the telephone the above description is taken, the articulation of this instrument is inferior to that of many others for long distances, although for short distances it is very good. Before proceeding to give an account of the manner in which the telephone is employed in commercial and every-day life, it will be of interest to notice briefly some special forms of telephonic apparatus.

Edison's Loud-Speaking Telephone.—This instrument is a most ingenious form of telephone receiver based upon the discovery made by the inventor that if a metallic plate were allowed to slide over certain prepared surfaces, such as chalk moistened with an easily decomposed electrolyte like potassic iodide, the frictional resistance to sliding could be very greatly diminished by passing a current through the contact. The instrument is shown in Fig. 51. A is a chalk cylinder, which can be turned at a regular speed by a set of multiplying wheels driven by the handle W. C is a strip of platinum supported by a thin mica diaphragm, and made to press with a constant pressure against the cylinder by the spring S, which is capable of adjustment by the screw E. The current from the transmitter flows through the support H to the chalk cylinder A, and thence through the platinum strip C and the wire D to earth.

When the cylinder is made to rotate, the friction between it and the strip C displaces the latter in the direction of motion, the displacement being greater the greater the friction.

Every variation in the undulatory current, sent through the contact by means of the transmitter, will produce a corresponding variation in the friction, causing the mica disk to vibrate in exact synchronism with the diaphragm of the transmitter. Instruments of this type were at one time supplied for use in private houses, but although they spoke much more loudly than the ordinary Bell receivers, they were found exceedingly troublesome, because the cylinder,

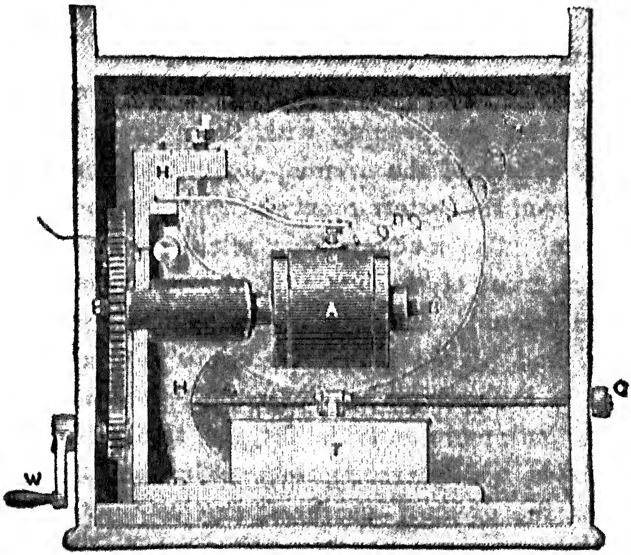


FIG. 51.

in order to work satisfactorily, must be neither wet nor dry, but only just moist, and therefore requires very careful attention. It acts best when it has been slightly moistened with a camel-hair brush from twelve to twenty-four hours before using it. To get really good results with this apparatus it is essential that the cylinder should be made to rotate with uniform velocity. This can be effected much more satisfactorily by means of clockwork than by hand,

but as the clockwork requires heavy weights to drive it, such an apparatus is more suited for exhibition than for practical use. When carefully adjusted, its reproduction of speech and musical sounds is very loud and distinct. It may be of interest to illustrate this by describing some of the results which I obtained when using a very fine instrument of this character, which had been loaned by the United Telephone Company for a lecture on the Telephone, delivered in the schoolroom attached to a church in Kensington. The telephone company had, in addition to lending this and other apparatus, kindly connected the schoolroom for the evening with their exchange system, and in the course of the evening communication was established between the lecture-room and the telephone exchange at Brighton. The loud-speaking telephone was placed on its stand in front of the platform, and stood about five feet above the ground. A cornet-player had been sent down to Brighton, and played his cornet opposite a carbon transmitter of a form somewhat different from either of those described, and more suitable for the transmission of the musical notes, which were reproduced by the Edison instrument with the greatest clearness, and so loudly as to be heard in every part of the lecture-hall. The voice of the speaker at the Brighton exchange was also very clearly reproduced; and although the reproduction was not so loud as in the case of the cornet, the words spoken were heard distinctly at a distance from twenty to thirty feet from the instrument.

The Photophone.—In the year 1873 Mr. Willoughby Smith discovered that when selenium was exposed to light its electrical resistance varied with the intensity of the light falling upon it, and shortly afterward Pro-

fessor W. G. Adams found that a ray of light falling upon a bar of selenium produced an E.M.F., causing the selenium under the influence of light to act like a small battery. Mr. Graham Bell and Mr. Tainter, after a long series of experiments, succeeded in constructing an apparatus in which this property of selenium was utilized for the reproduction of sound at a distance by the aid of luminous rays. The transmitter and receiver in their latest form are shown in Figs. 52 and 53. The transmitter, Fig. 52, consists of a simple telephonic box, B, provided with a mouthpiece and

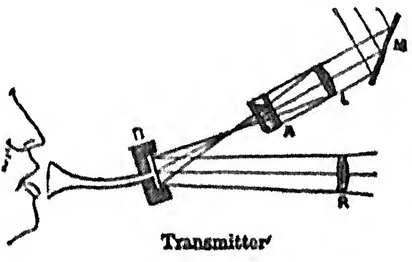


Fig. 52.

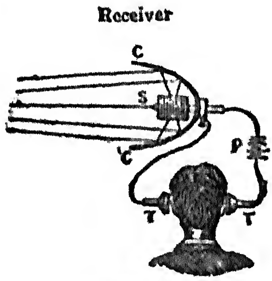


Fig. 53.

a membrane of mica plated with silver, forming a mirror on which rays of light are directed by means of an arrangement of mirrors and lenses, such as M, L, A in the diagram, from some powerful source, such as an electric lamp, or, better still, the sun. The rays, after reflection from the silvered surface of the membrane, are made parallel by passing through the lens, L, and the position of the instrument is adjusted so that these rays may fall upon the parabolic reflector, CC, of the receiver, shown in Fig. 53. This mirror is formed of copper, plated with silver, and in its focus is fixed a selenium cell, S, in circuit with the battery,

P, and a pair of telephones, TT, which are placed to the ears of the listener, as shown in the illustration.

Dr. Chichester Bell's Water-Jet Telephone Transmitter.—In the year 1886 Dr. Chichester A. Bell read a paper at the Royal Society on "The Sympathetic Vibrations of Jets," in which he gave an account of a series of experiments, some of which led to the invention of the water-jet transmitter. When a jet of water issues from a narrow orifice it gradually becomes discontinuous, breaks up into drops, as shown in Fig. 54, which is taken from an instantaneous photograph. One of Dr. Bell's early experiments in this direction consisted of producing sounds by communicating either mechanical or acoustic vibrations to a jet of this kind. The apparatus employed is shown in Fig. 55. It consists of a membrane of stretched India-rubber, forming a cap to a brass tube which can be raised or lowered by sliding in a larger tube resting on a heavy stand. The upper tube has an orifice at one side of the upper end, to which is attached a vulcanite trumpet. When a jet of water is allowed to fall upon the stretched membrane, either mechanical or sound vibrations communicated to the jet can be reproduced. The loudness and distinctness of the resulting sound both

Fig. 54.

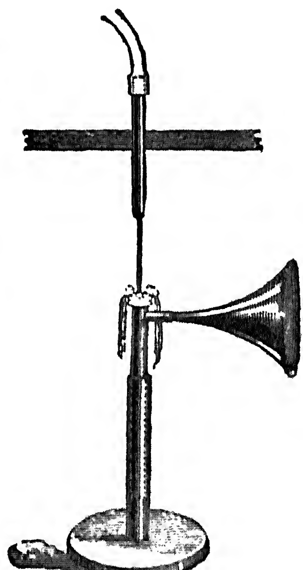


Fig. 55.

increase up to a certain point as the distance of the membrane from the orifice is increased, but after passing this point, though the sound continues to increase in loudness, it begins to lose its distinctness, until ultimately it becomes a mere unmusical roar, when it will be found that the jet has become discontinuous above the membrane. When the jet is carefully adjusted so as to obtain the best effects, the loudness of the sounds produced is very striking; for example, if the board to which the tube is attached is scratched with the finger, or if a watch is held in contact with the tube, the sounds produced can be heard distinctly throughout a room containing several hundred people. If the jet is allowed to fall upon the top of a narrow vertical rod, it spreads out into a nappe; and Dr. Bell found that this nappe was capable of responding to vibrations just like the jet, and it is this property which is utilized in the construction of the water-jet transmitter. The principle of the instrument consists in including the nappe of a jet of conducting liquid in a circuit traversed by a current from a battery, and containing an ordinary telephone. The nappe formed by the impact of a steady jet retains a constant diameter, but when thrown into vibration it undergoes periodic changes in diameter, and therefore also in resistance, which Dr. Bell considers to be due in part to the changes in diameter, and in part to changes in the contact resistance, arising from the motions of the particles of liquid, so that the current passing through the circuit undergoes corresponding continuous vibrations in strength, as in other forms of telephonic transmitters. The simplest way of passing a current through it consists in allowing the jet to strike normally upon the exposed end of a platinum wire imbedded in an insulator which is impervious to, and

unaffected by, the liquid employed, and which is surrounded by a platinum ring which comes in contact with the outer portions of the nappe.

The most suitable liquid consists of water acidulated with about $\frac{1}{300}$ of its volume of pure sulphuric acid.

The battery must be of high E.M.F., but its resistance is of little consequence, owing to the high resistance of the transmitter. A battery of about twenty small zinc-carbon cells, charged with a solution of sal-ammoniac, gives very good results with the liquid described, but the number of cells may be increased with advantage, not, however, to such an extent as to electrolyze the liquid, as the noise produced in the receiving telephone by the escape of gas bubbles would drown the sounds due to the vibratory changes in the jet. The pressure required increases with the size of the jet, and with jets of the most suitable size a pressure of a little under three feet of water gives the best results.

A simple experimental form of apparatus is shown in Fig. 56. The jet tube, J, is mounted on the sound-board S. The receiving surface is formed by the end, E′, of an ebonite plug. A platinum wire, E, passes water-tight up the plug, and its upper exposed surface forms the inner electrode of the transmitter. The outer electrode, E′, consists of a small tube of platinum foil concentric with the upper extremity of the wire E, and insulated from it by the ebonite. After it has been fitted on, the top of the ebonite plug is turned off, so as to present a smooth continuous surface, slightly convex.

Fine platinum wires welded to E and E′ serve to connect them with the terminals of the circuit. C is an ebonite cup which supports the plug, and receives the waste water which

escapes through the tube T. F is a filter, closed by screw caps, K and K′. Through the upper cap pass two tubes, X and Y, which are connected with a reservoir and the jet respectively, by means of black India-rubber tubing. Two perforated ebonite disks are fitted within the cylinder, and

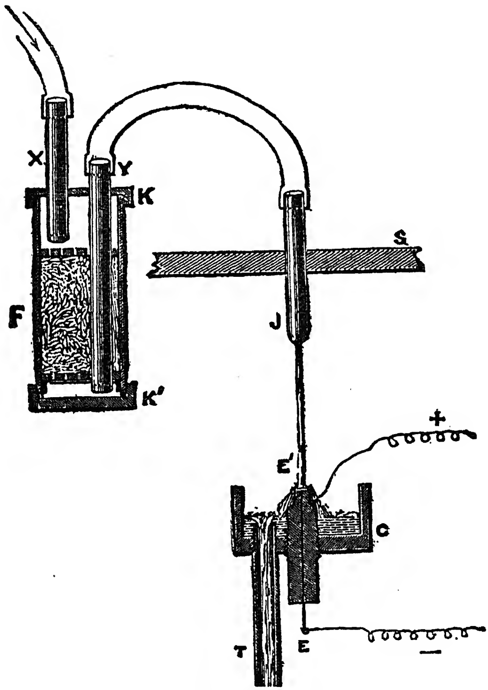


Fig. 56.

the space between them is tightly packed with coarse cotton, which has been freed from grease by soaking in a solution of caustic potash, and been thoroughly washed with dilute sulphuric acid and water. The filter is necessary to keep back particles of dirt which might stop the orifice, and also air bubbles, the presence of which sets up vibrations and gives rise to a crackling sound in the receiving telephone.

I have made some experiments with an instrument of this kind, but with the jet pressed laterally against the sound-board, which was about a quarter of an inch thick, and was fixed in a vertical position. It reproduced with perfect distinctness the voice of a person speaking in the tone of ordinary conversation at a distance of twenty feet from the instrument; and when standing in a room with an open window, it reproduced the sounds of a piano played in a room, in which there was also an open window, at the opposite side of the street. On another occasion I succeeded in obtaining an exceptionally clear and pure reproduction of the voices of four boys singing in unison in a room in which the transmitter was placed. When the Edison loud-speaker previously referred to was used with this transmitter, in place of an ordinary Bell receiver, very good results were also obtained. This form of apparatus is, however, not suitable for practical work, as in addition to its requiring separate vessels to act as reservoir, and to receive the waste liquid respectively, it requires careful adjustment whenever it is to be used. The inventor has recently devised an apparatus

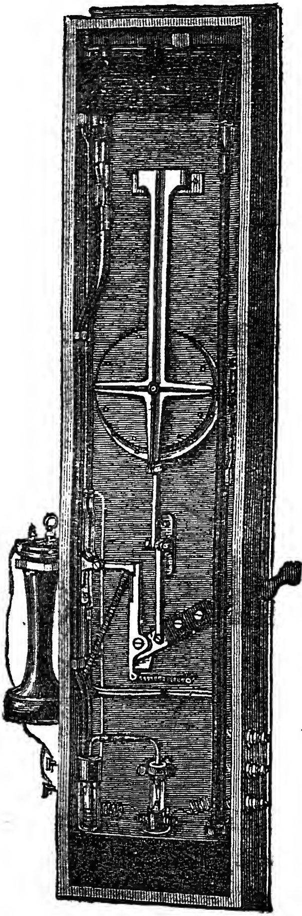


FIG. 57.

(shown in Fig. 57) which combines simplicity and certainty of action with durability. The whole apparatus is inclosed in a case of teak or mahogany about three feet high, and is protected in front by a cover which opens on hinges, and is provided with a lock and key. There is a round aperture protected by crossed copper wires opposite the transmitting jet, and in using the instrument the mouth of the speaker is placed at a distance of a few inches from this aperture, as it is neither requisite nor desirable to have a jet as sensitive as that of the experimental apparatus previously described.

The electrodes in this instrument are formed of a platinum wire passing up the centre of a glass plug and a concentric ring of fine platinum wire, glass being used instead of ebonite on account of its being found more durable. The jet and plug are contained in a glass tube attached to a wooden box, resting on the bottom of the case, which receives the waste liquid.

The glass plug is rigidly fixed in a vertical position, and the jet is centrally adjusted over it by means of the four screws shown at the upper end of the containing tube. The filter is seen on the left-hand side of the jet; its exit tube has its extremity enlarged into a bell which contains the cotton, and the fibres of this are prevented from passing into the narrow part of the tube by means of a piece of cotton material placed at the top of the bell. The reservoir consists of a second box similar to the first, placed at the top of the instrument, and is filled by taking out a screw plug in the centre of its upper side, and pouring the liquid in through a funnel.

The terminals of the receiving telephone are connected with the two left-hand binding screws, the lower one of

which is connected to one electrode of the transmitter, and the upper one to a pair of springs which make contact with the lever from which the telephone is suspended, when the latter is removed and the supporting hook is allowed to rise. The other electrode is connected with the lowermost of the binding screws on the right, which is put to earth through the battery; the central right-hand binding screw is in permanent connection through the call apparatus with the line, and also with a spring which makes contact with the telephone lever when the telephone is hung up. To speak through the instrument the telephone is taken off, but the hook end of its supporting lever is prevented from rising by means of the vertical lever shown. The handle on the right-hand side of the case is now depressed, when a pin on its lower end draws back the vertical lever and allows the telephone hook to rise, placing the telephone in circuit with the line.

The telephone lever in rising pushes up a brass rod hinged to it, thus lifting the left-hand end of the lever above the reservoir, and opening a valve which allows the fluid in the reservoir to flow down an ebonite tube on the left-hand side into the filter. A second ebonite tube passes from the filter and opens into the top of the reservoir to allow air to escape immediately, if the filter has run partially dry from the instrument remaining unused for some time. The depression of the right-hand lever at the same time compresses an India-rubber bag shown in the centre of the case, and thereby drives air into the lower box through an ebonite tube seen on the right-hand side, which is provided at its upper end with a valve opening inward, and forces liquid from the lower reservoir, through the other ebonite tube on the right hand, into the upper reservoir.

The amount of liquid pumped up by one depression of the lever is sufficient for about seven minutes' conversation, and as the average length of a conversation would usually be less than this, there will be enough liquid in the upper reservoir to allow of a longer conversation as often as it is likely to be wanted, without pumping up fresh fluid, which, however, does not interfere in any way with the conversation being carried on. The object of the control lever, which keeps the telephone out of circuit until the right-hand lever is depressed, is to prevent users from forgetting to pump up a fresh supply each time.

The instrument is chiefly valuable for use on trunk lines over long distances, as any leakage on the line can be compensated by using additional battery power, and very good results have been obtained with it on lines upward of a hundred miles in length, and passing through six or eight exchanges, and therefore subject to a considerable amount of leakage.

The Phonograph.—The phonograph is not an electrical instrument, and therefore some apology is needed for giving a description of it in a volume devoted to the practical applications of electricity. Historically, however, it is very closely related to the telephone, as it was Mr. Edison's telephonic investigations which led up to the invention of this instrument.

Graham Bell, by his invention of the speaking telephone, had made it possible for conversations to be carried on irrespective of the distance separating the speakers. Mr. Edison supplemented this by his invention of an instrument which in its present form enables spoken words and other sounds to be permanently recorded and reproduced at will at any future time. Some more or less suc-

cessful attempts have, moreover, been made by Mr. Edison to combine the phonograph with the telephone, so as to enable messages sent through the telephone to be recorded at the receiving station in the absence of a listener, and repeated by the phonograph at any convenient time.

These considerations, combined with the great interest attaching to the invention, will, I trust, be considered as affording sufficient ground for what at first sight might

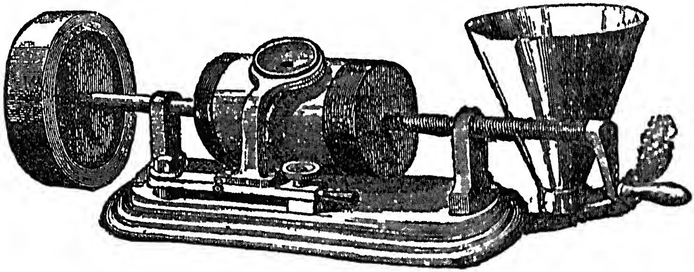


FIG. 58.

seem like a somewhat arbitrary deviation from the plan of the present volume.

The original form of the instrument, as designed in the year 1877, is shown in Fig. 58. It consisted of a brass cylinder upon which a spiral groove was cut, mounted upon a screw-threaded axis, and capable of being made to rotate, and at the same time move onward in the direction of its length, by means of a handle. A heavy fly-wheel attached to the end of the shaft opposite to the handle enabled an approximately uniform rate of rotation to be maintained.

A sheet of tin-foil was wrapped round the brass cylinder, and on this rested a metallic point attached to a metal diaphragm stretched underneath a mouthpiece, as shown in the illustration. When the mouthpiece was spoken into,

the diaphragm was set in vibration, causing the latter to vibrate up and down against the tin-foil just above the helical groove-cut in the cylinder, and make a series of indentations of varying depth in the foil. The reproducing arrangement consisted simply of a second diaphragm, held in a tube on the opposite side of the brass cylinder, and a metal point which was held against the tin-foil by means of a delicate spring. This mouthpiece could be placed in contact with the cylinder, or lifted off it, by means of a lever working upon a pivot, and when it was desired to reproduce speech or other sounds from the tin-foil record, this mouthpiece was simply placed against the cylinder, the trumpet shown at the right-hand side of the illustration being attached to the end of the tube to increase the loudness of the sound, and the cylinder was made to rotate in the same direction, and as nearly as possible at the same speed as while the record was being made. Much more satisfactory results were obtained from this instrument when the handle for turning the brass cylinder was replaced by means of clock-work, and a very beautiful instrument of this kind was made by Mr. Stroh; and was exhibited, together with an instrument of the original type, by Mr. Preece, at a lecture delivered before the Physical Society of London in March, 1878. This was the first public exhibition of the new invention in this country, and it excited the greatest interest, the lecture-room of the Society being crowded with members and their friends.

The meeting itself was perhaps the most uproarious meeting of a learned society on record; the mechanical reproduction, in a very "tinny" voice, of such familiar rhymes as "Old mother Hubbard went to the cupboard," and "We don't want to fight, but by Jingo if we do," the latter of

which was then a favorite music-hall ditty, exciting roars of laughter among the audience. Considerable amusement was excited by a gentleman who attempted to sing the words of "Auld Lang Syne" into the instrument. After completing the line "Should auld acquaintance be forgot," he found that he was singing too high, and he called out to Mr. Stroh, who was superintending the instrument, "Stop a minute; I will go on in a lower key!" This he proceeded to do, but as he had forgotten to take his mouth away from the instrument while making his sudden ejaculation, the instrument, in reproducing the song, stopped, and repeated the observation in exactly the same hurried tone in which it was originally made, after which it sang the rest of the song in the proper key.

Edison's original instrument, however, was nothing more than a toy, for in the first place it required very careful adjustment; and several attempts often had to be made, with a fresh piece of tin-foil each time, before the machine could be got to speak; and in the second place, after the sounds had been reproduced two or three times, the record became worn out; while, lastly, it was impossible to remove the tin-foil from the cylinder and replace it without injury.

Edison made a great many attempts to remedy these defects, and among others he tried the effect of using a wax cylinder with tin-foil stretched over it, and actually took out a patent for this arrangement. His attempts, however, were unsuccessful, and ultimately he laid the instrument aside, for reasons which it may be as well to give in his own words, quoted from an interview published in the "Electrical World"—a New York paper—on November 12, 1887. Speaking of the phonograph, Mr. Edison said—"It weighs about one hundred pounds; it costs a mint of

money to make; no one but an expert could get anything back from it; the record made by the little steel point upon a sheet of tin-foil lasted only a few times after it had been put through the phonograph. I myself doubted whether I should ever see a perfect phonograph ready to record any kind of ordinary speech, and to give it out again intelligibly. But I was perfectly sure if we did not accomplish this, the next generation would. And I dropped the phonograph, and went to work upon the electric light, certain that I had sown seed which would come to something." Mr. Edison's expectations were realized sooner than he anticipated. In the spring of 1881 an arrangement was made between Alexander Graham Bell, the inventor of the telephone, Dr. Chichester Bell, and Charles Sumner Tainter, resulting in the formation of the Volta Laboratory Association; this name being given to it because the capital with which the first start was made was provided by the Volta prize of 50,000 francs, which had been awarded to Graham Bell by the French Government for his invention of the telephone. The object of this partnership was stated to be "the study and elaboration of ideas, inventions, and discoveries relating to the art of transmitting, recording, and reproducing sounds."

The actual work was mainly done by Dr. Chichester Bell, a trained physicist, and Mr. Tainter, an exceedingly skilful and ingenious mechanic. The first part of their work consisted in studying the causes of failure in the phonograph, and they soon came to the conclusion that tin-foil or any other pliable substance was unsuitable, and that the record should be produced on a plate of some solid material; and also that a satisfactory reproduction could not be obtained by any process of indentation, but that a cutting

style must be used, adapted to grave or gouge out the material acted upon, in a groove, the bottom of which would thus be made to form a continuous wavy curve. This substitution of a continuous curve for the separate indentations of Edison's instrument was as great an improvement upon the original phonograph as that which Graham Bell had effected in the telephone by substituting a continuous undulatory current for the series of intermittent currents produced by making and breaking contact in Reis's telephone.

After trying a large number of substances, a kind of wax containing a considerable proportion of paraffin was found most suitable, and after some years of continuous work a phonograph was produced, capable of reproducing sounds with great clearness, and apparently an unlimited number of times, the same wax cylinder having been made to repeat the words engraved upon it more than a thousand times without showing any signs of deterioration.

The instrument was called the Graphophone or Graphophone-Phonograph, in order to distinguish it from Edison's original instrument. It was completed in the year 1885, and was exhibited privately to one of Edison's associates at Washington, and also to some members of the Edison Phonograph Company, which had been formed soon after the invention of the original instrument, and when it was still hoped that it might be made a practical success. The instrument was patented in the following year.

Its present form is shown in Fig. 59, which exhibits an operator speaking into the instrument, while Fig. 60 shows the operator receiving a message, and writing it down on a typewriter. The cylinders are made of paper covered with a thin layer of wax, and are held in position in the machine

Fig. 59

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by being gripped between conical projections on a pair of pulleys turning about axes in the same straight line. The cylinder is made to rotate by means of a driving-wheel worked by a treadle, and controlled by a governor of exceedingly ingenious construction, the invention of Mr. Tainter. This governor is so constructed that, as long as the speed

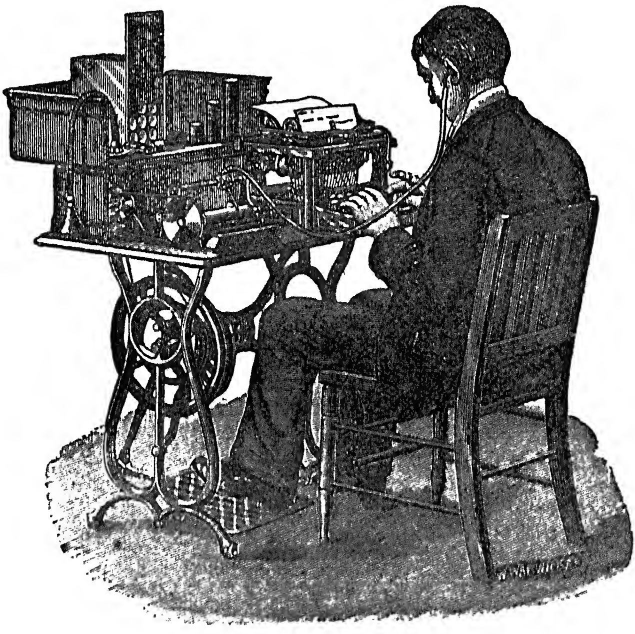


FIG. 60.

of the driving-wheel exceeds a certain minimum, the speed of the cylinder is maintained almost absolutely constant. The cylinder is not made to move forward as in the original phonograph, but, instead of this, the cutting style with its diaphragm, or the recorder, as the case may be, is made to move along an axle with a screw-thread cut in it, which rotates parallel to the axis of the cylinder. While

the machine is running, the motion of the cylinder and style can be started or stopped instantaneously by simply pressing a button, which is a great convenience both in dictating to the machine and in writing down from its dictation. In speaking to the instrument the operator is thus able, at the end of a sentence, to stop the motion of the cylinder, and so prevent any waste of space while he is thinking over the composition of his next sentence; and again, a clerk writing from the dictation of the instrument can take off as few words as he likes at a time, so that he can write down the record without any difficulty, either with a pen or upon a typewriter. Some of the instruments first made were constructed so as to speak loudly enough to be heard by a number of persons together without the assistance of a hearing tube.

This was effected by cutting the screw-thread of the axle which drives the recorder and transmitter rather coarsely, so as to leave a comparatively wide space between the different portions of the helix forming the record.

In all the instruments which have hitherto been imported into this country, however, the thread is cut much finer, with the object of enabling as many words as possible to be put on each cylinder, and thereby minimizing the number of cylinders required. This necessitates the use of hearing tubes, as shown in the illustration, Fig. 60. For practical use this does not cause any inconvenience. One of the great advantages of the graphophone for practical purposes is that, when the machines have been properly adjusted at the factory, no further adjustment is required in using them, and the cylinders can be put in or taken out in a moment.

Within the last year or two Mr Edison has again turned

Fig. 81

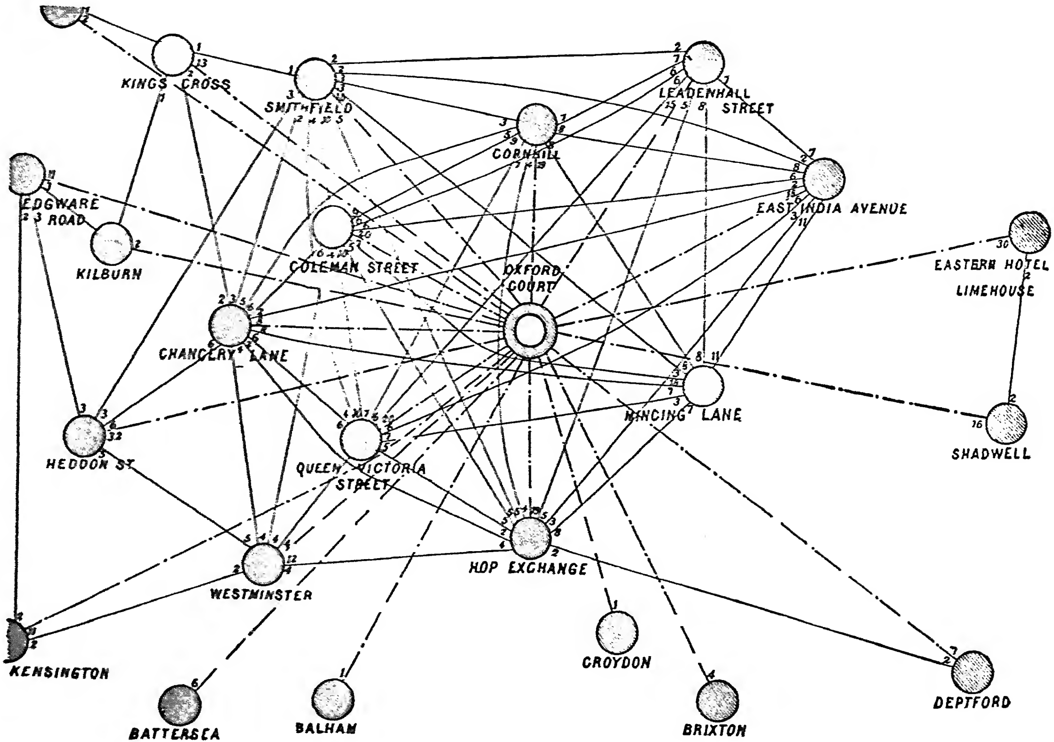


Fig. 62—Plan of London Telephone Exchange

Fig 62 is a plan of the exchange system existing in London at the beginning of 1888. The exchanges are denoted by circles, which are placed so as to make the diagram as simple a one as possible, and not in their relative geographical positions.

Each of the exchanges is connected by one or more trunk wires, as they are called, shown by dotted lines in the diagram, with the central exchange at Oxford Court, Cannon Street. The continuous lines show the wires connecting the local exchanges, and the small figures attached to these lines show the number of wires between each pair of exchanges. There are at present about five thousand subscribers in connection with this system of exchanges, including the subscribers at Brighton, which is in connection with the London system.

Every subscriber has a telephone fixed in his own house or office, and when he wishes to speak to another subscriber he goes up to his telephone and makes a call signal. This is transmitted to the local exchange with which he is connected, and one of the clerks at the exchange immediately replies to him. He then states the number of the subscriber with whom he wishes to speak, each subscriber having a certain number assigned to him. If the subscriber with whom he wishes to communicate is on the same local exchange, the clerk at once makes the required connection, provided the wire of the latter is disengaged—that is to say, if the latter subscriber is not actually using his telephone in speaking to some one else. If the second subscriber is on a different local exchange, the clerk, if there is a direct wire connecting the two exchanges, signals his number to the second exchange, and then the clerks at the two exchanges connect the telephone wires from the houses of

the two subscribers, through the wire joining the two exchanges. If, on the other hand, there is no wire directly connecting the two exchanges, the clerk at the first exchange calls the central exchange at Oxford Court, and indicates the subscriber with whom communication is to be established. The clerk at the central exchange then passes on the number to the proper local exchange, and the clerk there sends a call signal to the subscriber, and then connects him to the trunk wire at Oxford Court, so that the two subscribers are placed in communication through the central exchange.

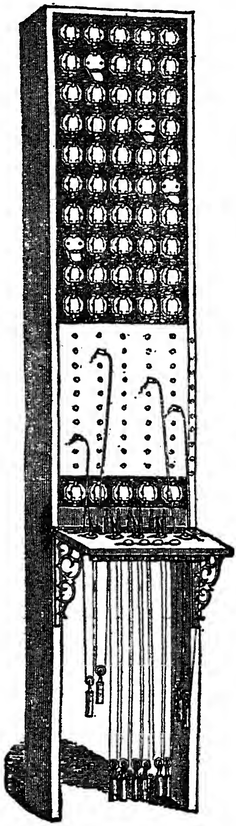
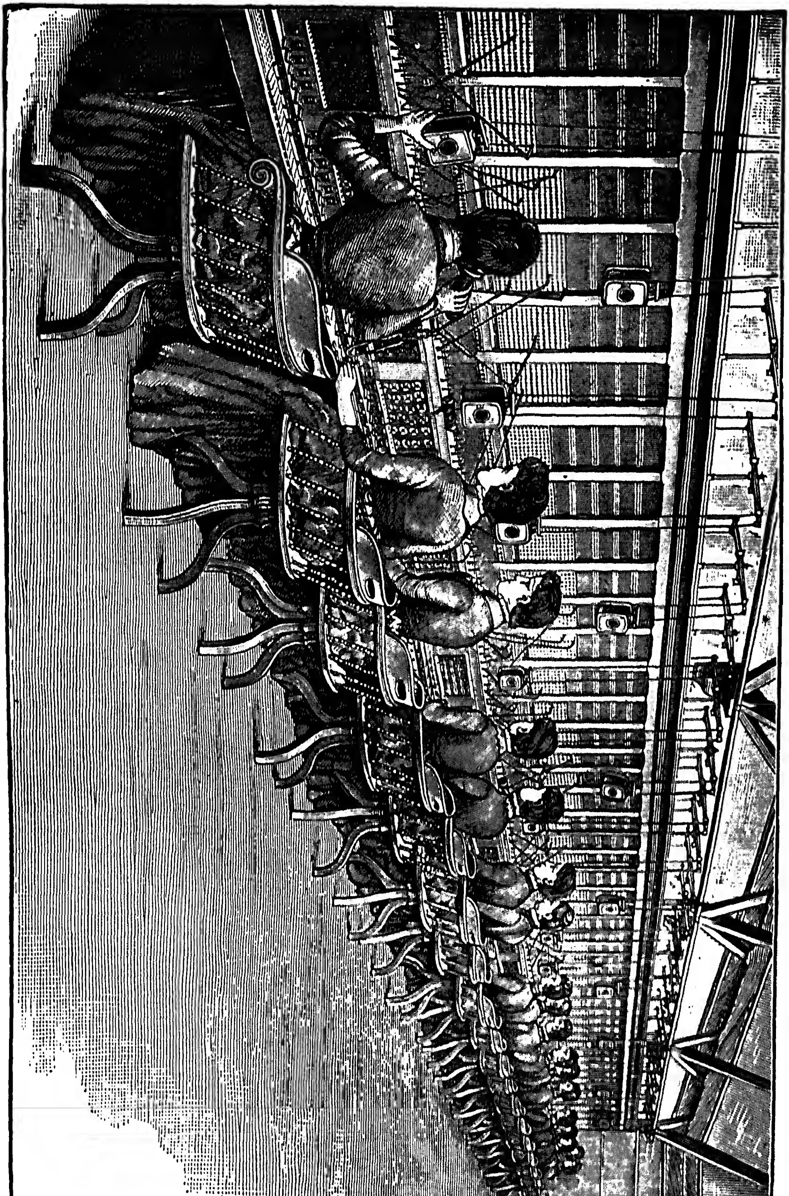


FIG. 63.

The manner in which these operations are carried out is fairly simple and easily understood. The set of telephone apparatus with which each subscriber is supplied consists of a carbon transmitter of the Blake pattern, a Bell receiver, a battery, and a small magneto-machine worked by a handle, for making the call signals.

The telephone is suspended from a hook similar to that used in the water-jet transmitter, described in Chapter XII. While the telephone is on its hook the subscriber turns the handle of the magneto to call the exchange; he then takes the telephone off the hook, thereby throwing the magneto out of circuit, and connects his receiver with the line as then described, except that the connection with the line is made



directly when the hook rises, instead of by the subsequent motion of a lever.

The exchange is provided with an instrument called a switch-board, and it will be easier to understand the process followed by considering in the first place a switch-board of a somewhat simpler construction than those usually employed in the London exchanges. Fig. 63 shows a simple form of switch-board adapted for fifty subscribers.

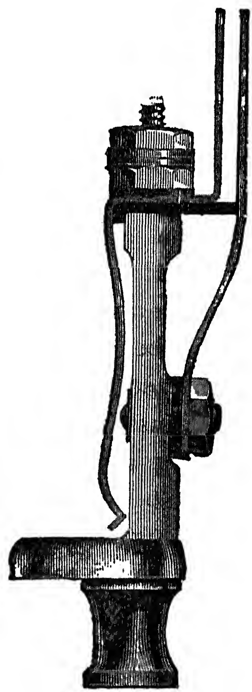


FIG. 64.

When the person who wishes to call the exchange turns the handle of his magneto, a current is sent through the line and the coils of a small electro-magnet placed at the back of the upper part of the board, immediately behind one of the drop-shutters shown in the illustration. The electro-magnet, being excited by this current, lifts a small catch, which allows the shutter to drop, disclosing the number of the subscriber. The clerk at the exchange then presses a plug connected with his own transmitter and receiver into one of the holes, shown in the lower portion of the board, marked with the same number as the one disclosed by the fall of the shutter. This connects the operator by means of what is called a "spring-jack," shown in Fig. 64, placed at the back of the board, with the calling subscriber.

The contact plug passes through the collar shown in the lower part of the illustration, and makes contact with the left-hand spring at the same time lifting it off the

contact button shown, and thereby breaking its connection with the right-hand spring. The left-hand spring is insulated, and in connection with the calling subscriber's wire, while the right-hand spring is earth-connected. When the operator has introduced his plug, he replies to the calling subscriber by means of his transmitter, and then listens at his receiver until the subscriber who called has stated the number of the subscriber with whom he wishes to communicate.

When this has been done the operator inserts his plug into the opening of the spring-jack corresponding to the subscriber who is to be called, and presses a key, which sends a current into the line, from a battery or other generator at the station, and rings the latter subscriber's bell. The operator then removes his own plug and places the two subscribers in connection by taking up a pair of plugs connected by means of a flexible wire cord, as shown in the illustration. They can then carry on conversation as long as they wish, and when they have finished each subscriber turns the handle of his magneto, and the current from this causes one of the clearing-out drops at the bottom of the board to fall, indicating to the clerk at the exchange that his line may be cleared. Subscribers often forget to give the clearing-out signal when they have finished their conversation, and an automatic arrangement is therefore sometimes adopted, which sends a clearing-out signal as soon as the subscriber has replaced his telephone upon its hook.

If a number of switchboards, such as that shown in Fig. 63, were used in an exchange in connection with a large number of subscribers, arrangements would have to be made for making connections across from one board to the other,

and an operator on one side of the room would frequently have to shout across the room to one on the opposite side in order to tell him to make the required connection. An arrangement of a similar character was actually employed in the earlier exchanges. The method, however, is very inconvenient, owing to the confusion caused by operators calling to each other from all parts of the room, and the multiple switchboard, a comparatively recent invention, is now gradually displacing all such systems.

The general arrangement of a multiple switchboard is shown in Fig. 65, which illustrates the multiple board at the Manchester Exchange, and shows the operators at work. Each operator has to attend to a group of as many subscribers as she can conveniently serve, and the drop-shutters and annunciators belonging to these groups of subscribers are seen on the lower section of the board. Each subscriber to the exchange is connected to a group of spring-jacks placed on the upper section of the board, and distributed in such a manner that one of them can be reached by every operator without moving from her place. The plugs for making the connection, and the flexible conductors connecting them, are the same as those already described, but the spring-jacks are slightly modified, being constructed and connected up in such a manner that the line coming from a subscriber passes behind the board and through all the spring-jacks of the same number without touching their metallic framework, and finally goes from the electro-magnet of the annunciator to earth. When a plug is introduced into one of the switch-holes, for instance, that of the middle section of the board, the line passes directly to the plug and its flexible cord. To explain how

connection is made between the subscribers, suppose that No. 25 has called the exchange.

The shutter of his annunciator then falls, exposing the number, 25, and the operator takes a pair of plugs attached to one of the flexible cords, and inserts one of them into the spring-jack No. 25, at the same time depressing a key at the bottom of the board, which places her own set of telephone apparatus in circuit with the telephone wire of the calling subscriber. She then inquires what number he wishes to speak to, and I will suppose that No. 25 informs her that he wishes to speak with No. 875. The clerk then touches the spring-jack No. 875 with the plug attached to the further end of the flexible cord, one end of which is already in connection with No. 25. If the line is engaged she will then hear a noise in her telephone, but if no noise is heard she knows that the line is free, and she then inserts the plug and presses a second key, sending a current from a generator at the exchange to No. 875, thereby ringing his bell. She then lifts her hand from the call key, and the two subscribers are in communication. When the conversation is finished the subscribers turn the handles of their magneto call bells, causing the clearing-out drops to fall, and the operator then removes the plugs, which fall back, owing to the counterpoise attached to them, to their original position.

In this country the use of the telephone is almost entirely confined to business men, and to them it is of the utmost possible value, owing to the rapidity with which communications can be made and replied to. In all the large American towns, however, it is extensively employed in private houses; and, as all the principal shops are on the exchange, the mistress of a house can sit down to the telephone and order whatever she may require during the day.

The houses or offices of the professional men, and the cab-stands, are also in connection with the exchange, so that, for example, if a doctor is wanted in a hurry he can be called in a moment by telephone, and on receiving the message he can at once call for a cab, which he will find waiting at the door almost as soon as he is ready to start. Fire and police stations are also in connection with the exchange, so that if a fire breaks out in the house, or if burglars break in during the night, assistance can be obtained at once.

I will conclude this chapter by an instance, which came within my own personal knowledge, of the value of the telephone for such purposes. A banker at a town in the United States was one night absent from home, and his wife was left with only women servants in the house. After she had retired to rest she heard some noise proceeding from the lower part of the house, which led her to believe that burglars had obtained an entrance. She at once got out of bed as quietly as possible, went into her dressing-room, where a telephone was placed, called the police and asked for assistance. In the course of a very few minutes a party of policemen arrived and captured three negroes who were engaged in robbing the house.

CHAPTER XIV

DISTRIBUTION AND STORAGE OF ELECTRICAL ENERGY

THE great extent to which electricity is now being employed for lighting purposes, and also for driving machinery, makes the question as to the most efficient and economical means of distributing and storing electrical energy one of great and increasing importance.

When the electric current has to be carried to any considerable distance, the electrical energy can be transmitted with greater economy, the higher the electro-motive force of the current. The reason of this is that the amount of energy which can be obtained from a current does not depend merely on the strength of the current, but is proportional to the strength of the current multiplied by the electro-motive force by which it is driven through the conductor. The case is very similar to that of distributing water for the purpose of driving machinery by means of turbines, the amount of work that can be obtained by passing a given volume of water through a turbine increasing with the pressure at which the water is supplied.

Now it has been pointed out in an earlier chapter that when an electric current traverses a conductor a certain amount of its energy is wasted in the form of heat, and the quantity of heat developed being proportional to the square

of the current strength and to the resistance offered by the conductor, it follows that with a high electro-motive force a smaller current will be required to supply a given amount of energy than when the electro-motive force is low, and therefore smaller wires can be used for conveying it without leading to an undue production of heat.

In the case of currents supplied from central stations for electric lighting and other purposes, the electro-motive force, or electric pressure, developed by the dynamos is usually about two thousand volts. Currents at this pressure can be employed directly for supplying energy to a number of arc lamps, connected in series, for lighting open spaces or large public buildings, where the lamps do not have to be lighted up or put out one at a time. It would not do, however, to introduce a current of this pressure into a private house, for in the first place it would be exceedingly dangerous to life, and is therefore forbidden by law; and even if it were allowable, it would only be possible to use it for incandescent lighting, by joining a very large number of lamps in series, and starting or putting them all out at the same time.

Some method must therefore be adopted of transforming the current down to a much lower pressure. If the current is only to be used for electric lighting, it may be supplied directly to the houses from alternating dynamos at the central station, and transformed down to a low pressure, generally about one hundred volts, on entering the house, by means of a piece of apparatus known as a transformer. This instrument is very similar in its general character to the induction coils described in a previous chapter.

It will be remembered that an ordinary induction coil consists of a short thick coil of copper wire, wound round

an iron core, and carrying a current of low electro-motive force. This current is made intermittent by means of a contact breaker, and at make and break, secondary currents are induced by it in a very much longer coil of fine wire wound outside the primary coil. By means of such an instrument a current of low electro-motive force is made to give rise to one of much smaller strength, but of correspondingly higher electro-motive force. A transformer may be considered as practically an induction coil in which the primary and secondary currents are interchanged, and the contact breaker is done away with, since the current is an alternating one as it comes from the dynamo.

In this system the circuit containing the lamps in a house is complete in itself, and has not any direct connection with the dynamo circuit. The currents which energize the lamps are secondary currents of low electro-motive force, but of considerable strength, produced by a primary current of much higher electro-motive force and lower strength. The transformer is fixed in any convenient place in the house, being inclosed in an iron case and kept under lock and key, so that the dangerous currents are inaccessible to the inmates of the house.

Another method of distributing the current is by means of secondary batteries. It has already been pointed out that no primary battery has yet been discovered capable of supplying electric current economically upon a large scale; but not many years ago Planté discovered that when an arrangement composed of lead plates, having their outer surfaces reduced to a spongy form, and immersed in dilute sulphuric acid, was traversed by an electric current, the resulting chemical changes transformed it into a battery, so that when the charging circuit was interrupted, and the plates

which had been connected to the two terminals of the dynamo, or primary battery, used for charging, were connected with each other, an electric current was produced, accompanied by a gradual restoration of the cell to its original condition, and that when this was attained the current stopped.

The name of secondary battery or accumulator has been

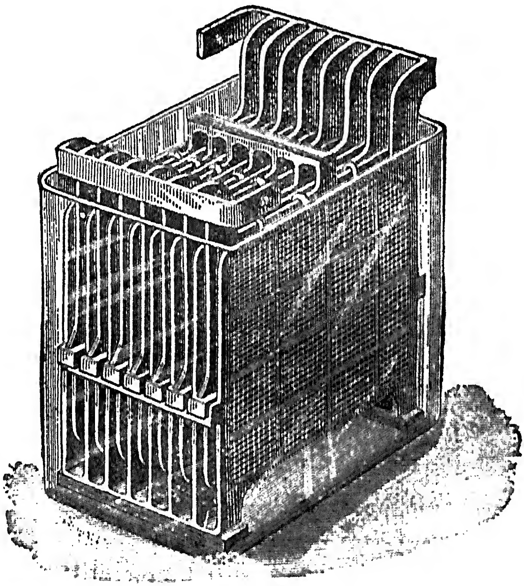


FIG. 66.

given to a cell of this kind, which acquires the property of producing an electric current by having a current passed into it. The original Planté accumulator has been considerably improved by Faure and others, and one of these cells, as now constructed by the Electrical Power Storage Company, is shown in Fig. 66.

The plates are made of sheets of lead perforated with a number of square pyramidal holes, filled up, in alternate

plates, with a paste made of red lead and sulphuric acid, and litharge and sulphuric acid respectively.

The terms accumulator and storage battery are now in very general use, but the reader should bear in mind that what is stored up is not electricity, but electrical energy—that is to say, the power of producing an electric current. Storage batteries may be used instead of transformers in distributing the current from the central station, but, as they require skilled attention, they cannot be placed in the houses of consumers, and therefore have to be distributed among sub-stations, each of which supplies a group of houses in its immediate neighborhood.

The cells at each sub-station are connected up into a series of groups arranged in series—that is to say, with the positive plate of one cell in connection with the negative plate of the next, and so on; and in order to charge the battery, the high potential current from the central station is allowed to flow into a set of several groups coupled up in series.

When the batteries are charged, the groups are disconnected and connected up in parallel—that is, all the negative terminals connected together, and likewise the positive terminals, the cells in each group being still connected in series. The number of cells in a group is regulated so as to give a current of the desired electro-motive force from the sub-station to the consumers. The current provided in this way, being continuous in direction, is valuable, not only for electric lighting, but for driving motors or electro-plating. Alternating currents are not at present used for working electro-motors, as no satisfactory form of motor has yet been devised to work with such currents. The mains carrying the currents from a central station may

either be carried overhead on poles or laid underground. In towns they are usually carried underground, as the heavy cables required to carry large currents are not only unsightly when carried overhead, but form a source of danger in case of breakage, owing to their great weight, and to the fact that they carry currents dangerous to life. Distribution by means of accumulators has the advantage of enabling the electro-motive force to be kept extremely constant, and this is of the greatest importance in electric lighting, as any variation in the electro-motive force causes a fluctuation or flickering in the light. Another great advantage of the system of distribution by means of accumulators is that a much smaller plant is required at the central station, because, under ordinary circumstances, the demand for current will be much greater at certain periods out of the twenty-four hours than at others, and when accumulators are used the dynamos can be kept at work charging them during the time when the demand is slack, thereby storing up energy to meet the heavy demand during the busier part of the day. When the distribution is effected by means of transformers, sufficient engines and dynamos have to be provided to meet the greatest demand that can possibly be made upon the station, and arrangements have to be made for throwing additional dynamos into the circuit as the number of lamps turned on increases, and this has to be done without causing any flickering in the lights, which would be a great annoyance to consumers.

The disadvantages of accumulators are—their high initial cost, the expense of maintenance and renewal, which is considerable, and the fact that they waste a much larger proportion of electrical energy than is done by a well-constructed transformer.

There is another method for using current in the mains of a higher electro-motive force than is suitable for incandescent lamps or electro-motors, consisting in the employment of a special method of distribution, known as the three-wire system, which was patented by Dr. Hopkinson in the year 1882.

It is only applicable to the distribution, at comparatively low pressure, of continuous currents, and is therefore not suitable for use at central stations which have to supply large districts. It is of great value, however, when all the houses supplied are included within a small area.

It is not in that case necessary to employ a very high pressure in the mains, but it is of great advantage to employ a higher one than can be applied directly to the lamps. For example, the highest E.M.F. at which glow-lamps have been constructed to work is 100 volts, and by means of the three-wire system a pressure of some 200 volts may be employed in the mains. This is advantageous in two ways. In the first place, it reduces the effect of small variations of potential at the dynamo terminals. For example, in the case considered, a variation of 5 per cent in the E.M.F. in the mains would produce a variation of only 2½ per cent at the lamp terminals, so that the lamps would burn much more steadily. It also enables a much smaller weight of copper to be employed in the mains, and thereby greatly reduces the cost of the installation, and enables the light to be supplied with profit at a lower rate than would otherwise be possible.

In this system two dynamos are employed, the negative terminal of one being attached to one main, called the negative main, and the positive terminal of the second dynamo to the other, or positive, main. The other terminals of the

two dynamos are attached to a separate main known as the balancing wire, and the lamps and motors each have one of their terminals connected with this balancing wire, while the others are attached, in as nearly as possible equal proportions, to the positive and negative main respectively. If the resistances of the lamps and motors in the two circuits are exactly equal there will be no current along the balancing wire, and the greater the inequality the greater will be the current along this main. As the balancing wire has to carry much less current than the other two mains it is made much smaller, and this system of distribution is found to effect a considerable saving in the amount of copper necessary for the mains.

When the electric current is carried from a central station to houses at a considerable distance the electro-motive force gradually diminishes as the distance from the station increases, and, as has been explained in a previous chapter, the fall of potential between any two points is proportional to the resistance between them; so that, if a good many consumers are supplied from different points of the same main, the lamps of those at a greater distance will not be nearly as bright as those close to the station. In order to remedy this defect as far as possible, a system of feeders should be employed—that is to say, a series of mains should be provided running from the central station to various distant portions of the house mains, no current being taken off at any intermediate portion of the feeder.

This system is extensively used on the Continent with very satisfactory results, but hitherto it has not been very generally introduced into this country. When street lamps are lighted by electricity the current is usually supplied at an annual charge for each lamp, definite stipulations of

course being made as to the number of hours during which the lamps are to be kept alight. In private houses, however, or in factories or workshops where the current is used either for giving light or for working electro-motors, the current is usually charged for according to the amount consumed.

Meters which measure the amount of current passed through them, just as gas-meters measure the amount of gas, are fixed in the houses; but these meters do not, as in the case of gas-meters, absolutely insure the consumers getting what they pay for, for the electrical energy obtainable from the current depends on the electro-motive force as well as on the quantity, so that if the former is allowed to fall below a certain value the consumer will be paying too high a price for his supply. Unfortunately, no completely satisfactory simple meter has yet been devised for measuring electrical energy instead of simple current strength; but a good many inventors are working at the subject, and we may hope that before long they will be successful in producing a simple and efficient meter of the kind so urgently required.

The different forms of meter employed for measuring the amount of current supplied are far too numerous for me to attempt to give a detailed description of them, for hardly a week passes without a new one being patented.

The first current-meter was invented by Edison, who exhibited it at the Paris Exhibition in 1881, since which time it has been very largely employed in measuring currents supplied from central stations. In its original form this meter consisted of a pair of copper plates suspended from the ends of a balanced beam, and dipping into a solution of sulphate of copper.

A continuous current passing through the solution carried the copper from one plate and deposited it upon the other until the difference of weight was sufficient to tip over the balanced beam. When this happened it was registered by means of a counting mechanism, and at the same time the direction of the current through the meter was reversed, so that the copper was carried from the heavy to the light plate until the latter became heavy enough to tip up the beam and again reverse the current.

In this way the process went on continuously. The whole of the lighting current was not sent through the meter, for unless this were to be made of immense size the resistance would be so great as to reduce considerably the strength of the current, and therefore the meter was attached as a shunt to the main circuit, and was traversed only by a fraction of the whole current.

The meter in this form was, however, found to be open to serious objections. The resistance of electrolytes is always found to diminish as the temperature increases, while that of metallic conductors increases with the temperature. In hot weather, therefore, the resistance of the sulphate of copper would be diminished, while that of the copper lead would be increased, causing a larger proportion of the total current to go through the meter in hot weather than in cold.

The making and breaking of contact necessitated by the use of a commutator, for reversing the current, also led to endless trouble, so that the meter had to be modified, and in its present form zinc plates dipping into a solution of sulphate of zinc are employed. The plates are examined and weighed once a month, and fresh ones are inserted as the old ones are worn out. A thousandth part of the total

current is usually sent through the meter; and the proportion of current going through the meter is maintained fairly constant within a considerable range of temperature, by placing a copper resistance in series with the solution, so that when the temperature rises the increase in the resistance of the copper may balance the decrease in the resistance of the solution. The alternative path of the current is made of German silver, the resistance of which changes very little with the temperature. These meters may be depended on to about 3 per cent, and are in very general use.

Professors Ayrton and Perry have designed an entirely different type of meter intended to fulfil the condition, the desirability of which I have already pointed out, of measuring the electrical energy directly instead of merely the strength of the current.

The instrument consists essentially of a good clock, the pendulum bob of which is formed of a coil having a resistance of about a thousand ohms. A coil of short thick wire, having only a small resistance, is fixed to the clock case, parallel to the coil forming the pendulum bob.

The current, as it enters the house, passes through this coil of thick wire, from which it is carried to the lamps, motors, or other electric machinery in the house, and then passes away to the street main, or to another house. The terminals of the fine wire coil of the pendulum pass up the pendulum rod, and one of them is connected to the terminal of the thick wire coil where the current enters, the other being connected, by means of a fine wire, to the house main where it leaves the house.

The current passing through the pendulum bob will then depend on the difference of the electro-motive forces in the main, where it enters and leaves the house respectively,

whereas the current passing through the thick wire coil is practically equal to the total current working the lamps and motors. Now the amount of energy absorbed in the house is proportional to the product of the strengths of these two currents, and whatever variation may take place either in the strength of the current, or in the electric pressure, the loss of the clock in that time, due to the mutual actions of the currents, will be exactly proportional to the amount of energy absorbed. This meter has been somewhat modified and improved by Dr. Aron in Germany, and is used in connection with the Berlin central stations.

Among the meters which have been designed for use with alternating currents I will only mention two as types.

The first of these has recently been devised by Mr. Schallenberger, electrician to the Westinghouse Company at Pittsburg, in the United States. It consists essentially of a circular iron disk mounted upon a vertical axis, and connected with a train of mechanism to count its revolutions. A coil of wire carrying the current to be measured is wound round one of the diameters of this disk, and a second coil, having its terminals connected together, so as to form a complete circuit in itself, is wound round a second diameter, which is inclined to the first at an angle of 45°. When the alternating current is sent from the first coil a series of secondary currents are produced in the other. Now the main current will at any moment magnetize the iron disk in a certain way, and, as the result of this magnetization, the secondary current induced in the other coil will make the disk begin to rotate. When the primary current falls to zero the induced current will magnetize the disk, and the arrangement is such that the reaction between this magneti-

zation and the following current in the circuit will continue to cause rotation in the same direction.

The other meter was invented by Professor Forbes, and is suited for the measurement either of continuous or alternating currents, as its indications depend on the amount of heat developed by the current passing through a short spiral coil of thick wire fixed horizontally within the meter. The heating of this coil sets up convection currents in the air, which turn a sort of small windmill arrangement fixed above the coil. The vertical axis about which the windmill turns is connected with a train of wheelwork which serves to count the revolutions, and the amount of current which has passed through the meter will therefore be known when the relation between the total amount of current—viz., the product of the current strength by the time—and the number of revolutions, has been determined once for all.

CHAPTER XV

ELECTRIC LIGHTING

IF a strong electric current, such as may be obtained from a dozen or more Grove cells, is passed through a circuit containing two pieces of carbon in contact with each other, the resistance at the point of contact is so great that the carbons will become white hot. If they are then separated a short distance an arc of light will be formed between them, the carbon in the meantime gradually burning away, especially the one in connection with the positive terminal of the battery. When the distance between the two carbon points exceeds a certain amount, depending on the electro-motive force in the circuit, the arc will be extinguished, and cannot be obtained again until the carbons are brought into actual contact, as the electro-motive force of the battery is not sufficient to drive a current through an appreciable thickness of air resistance, though it can maintain the current across the arc when this is once formed, owing to the resistance of an arc of a given length being incomparably less than that of the same length of cool air.

For a good many years light obtained in this way has been used to a considerable extent when a very strong light was required for lecture experiments, and sometimes also

for magic lantern exhibitions, when cost was not a matter of great importance. As, however, independently of the initial cost of the batteries, the zinc and acid used in maintaining a single bright arc light for a few hours might cost from ten shillings to a pound, it is clear that it would be quite hopeless to think of employing the electric light obtained in such a manner for general lighting purposes.

The invention of the dynamo, however, makes it possible to produce electric current by the consumption of the comparatively cheap fuel, coal, instead of the more costly zinc, which is the fuel usually employed in primary batteries.

There are two distinct systems of electric lighting adapted to meet totally different requirements—viz., the systems known respectively as Arc Lighting and Incandescent Lighting.

Arc Lighting.—The electric arc which I have just described gives an exceedingly powerful light, and when protected by globes of opal glass or other translucent substance, to shade the eye from the direct glare of the light, it is extremely suitable for street lighting and for use in railway stations, factories, and other large buildings.

The number of different kinds of arc lamp is almost innumerable, but those employed for ordinary lighting purposes are invariably automatic—that is to say, they are provided with some arrangement by means of which the carbon points, as they burn away, can be maintained at an approximately constant distance apart. The only way of doing this that has really proved a practical success consists in the use of some electro-magnetic arrangement, according to which, when the distance becomes too great, the weakening of the current, by diminishing the magneti-

zation of a small electro-magnet, allows its armature to fall, and sets in motion a train of mechanism by which the carbon points are made to approach each other, thereby diminishing the resistance, so that the current is again able to magnetize the electro-magnet sufficiently to stop the mechanism.

The lamps employed at the time when the electric light was only used for lecture purposes were exceedingly complicated in structure, and were moreover very unsatisfactory, as the regulation was far from perfect, the light at times becoming dim and then suddenly flashing out into its original brilliancy. Most of those, however, which are now in use are very satisfactory, as may be seen from the steadiness of the arc lamps in any well-managed installation.

Arc lamps are usually connected together in series, and are supplied with a constant current. Many of the circuits are of a considerable length, some in America attaining to as great a length as twelve miles, while circuits of eight miles in length are frequently employed by the Thomson-Houston Company, who have carried out a very large number of installations both in America and in Europe. The steadiness of the light will not only depend upon the mechanism of the lamps, but quite as much upon the mechanical and electrical governors employed for maintaining the constancy of the current. Defects in the regulating apparatus are chiefly noticeable when lamps are switched into or out of the circuit, as, in order to prevent fluctuations in the light, the governing apparatus must be sufficiently sensitive to cause the dynamo to respond at once to the demand made upon it for extra current, or to supply a smaller current when the load is diminished, and even if the electrical governing system is all that can be desired, the engine governor

must likewise be extremely sensitive, so as to enable the engine to begin at once to supply the extra amount of work when additional lamps are thrown into the circuit, or to supply less work when lamps are cut out. If the lamps are supplied from accumulators, then of course the regulation of the engine ceases to be a matter of primary importance. The number of lamps included in any one dynamo circuit will depend of course upon the capacity of the dynamo, upon the current absorbed by each lamp, and upon the difference of potential which is to be maintained between its terminals. The quality of the carbons also exerts an important effect on the steadiness of the light unless the electrical regulation is extremely good.

The first experiments on the production of an electric arc between carbon points were made by Sir Humphry Davy with carbons consisting simply of sticks of wood charcoal, but it was soon found that this material was much too soft for the purpose, as it burned very rapidly, giving off numerous sparks. Recently, however, Gaudin has gone back to the use of rods of wood charcoal, which, however, have their density very greatly increased by being soaked in some liquid hydrocarbon, in order to fill up their pores, and are then fired, the process being repeated until the desired density is obtained. The first improvement in the carbons used for producing the electric arc is generally considered to have been made by Foucault, and consisted in replacing the rods of wood charcoal by rods sawed out of gas carbon. The principal points which have to be aimed at in the manufacture of carbons for arc lighting are, in the first place, to obtain a carbon of regular density, of as low electrical resistance as possible, and free from admixture with other substances; and in the second place, to produce

rods of sufficient length to burn as long as may be required, perfectly straight and cylindrical in form. Various processes are employed to attain these results, and the manufacturers usually do their best to keep them secret; but the general procedure in all of them consists in first reducing coke or graphite to a fine powder, and then washing it with an alkaline solution, to free it from silica and earthy impurities; after this it is formed into a stiff paste by mixing it with a sufficient quantity of some tarry hydrocarbon, and the paste is then forced under pressure into molds of the required form. When the rods are taken out of the molds they are dried and packed in air-tight boxes, the empty spaces between the rods being filled up with coke dust, after which they are fired in a kiln. It is generally found necessary to repeat the process of soaking in hydrocarbon, with the subsequent firing, at least twice, and in the case of the best carbons it is usually repeated several times.

When a sufficiently sensitive system of electric government is employed, very good results can be obtained even with inferior carbons, and many of my readers will probably remember the lighting of the American and Italian Exhibitions in London in 1887 and 1888, which were carried out on the Thomson-Houston system; and although the commonest American compressed carbons were employed, the steadiness of the light was everything that could be desired.

Arc lights are extremely suitable for use in lighthouses, as the great brilliancy of the light enables it to be seen at a considerable distance, even in foggy weather. This was recognized at a comparatively early period, and before the invention of the modern dynamo, which first made possible the general introduction of the electric light, several of the more important lighthouses were provided with arc lights.

the current of which was supplied from large magneto machines, built up of a great number of permanent magnets, with coils revolving between them. Most of our ironclads

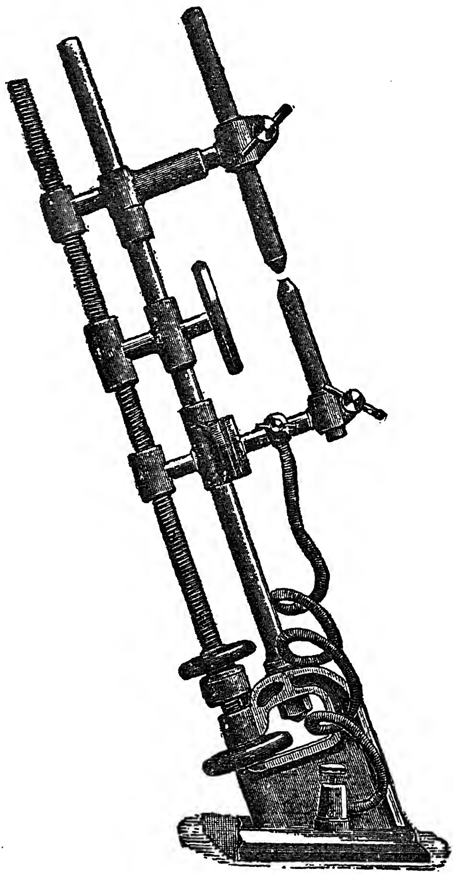
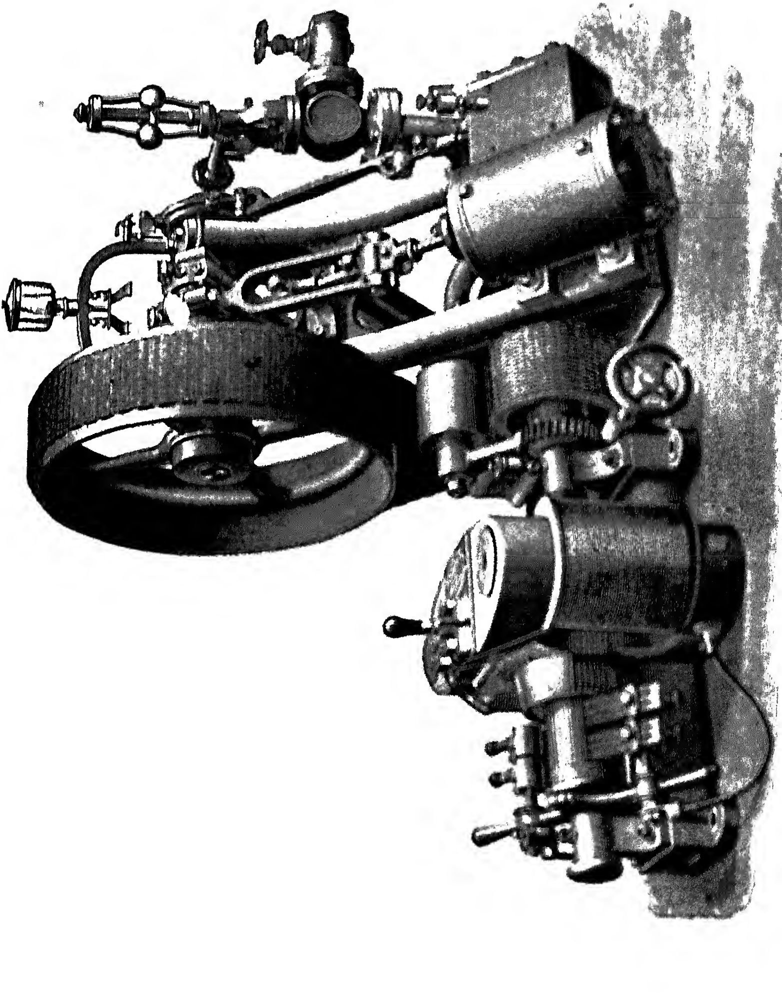


Fig. 67.

are now supplied with powerful arc lights, provided with reflectors, and known as search-lights, to enable them to discover the presence of torpedo boats, and to destroy



them, by aid of their quick-firing guns, before they have got near enough to do any damage.

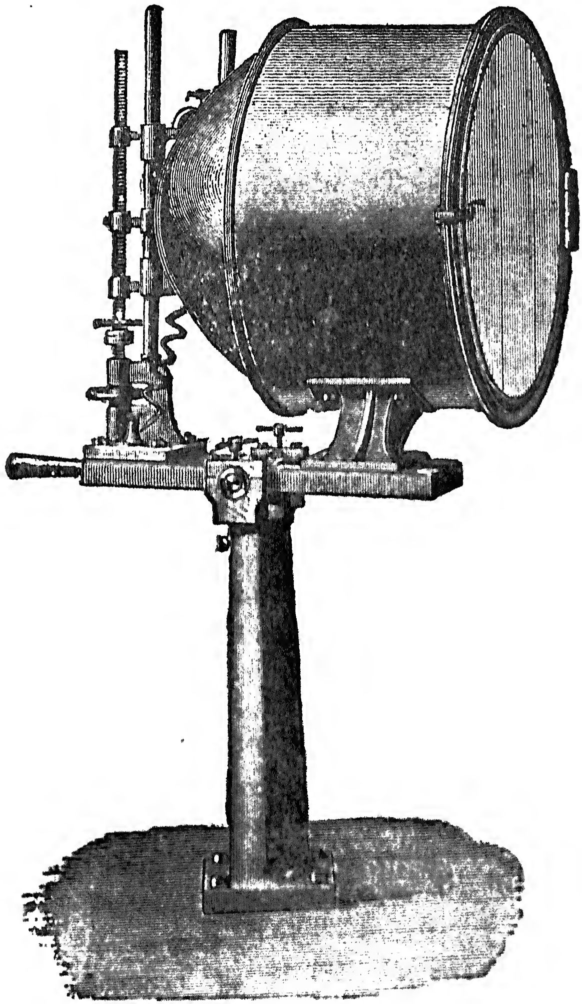


FIG. 88.

What are known as hand-feed lamps are usually employed for search-lights—viz., lamps in which the carbons

are manipulated by hand instead of by an automatic arrangement. Fig. 67 illustrates a simple form of hand-feed lamp, manufactured by Messrs. Ernest Scott & Co., of Newcastle, and designed for search-lights, or for use with microscopes or magic lanterns.

For use as search-lights these hand-feed lamps are provided with a system of lenses for concentrating the light into a single beam. The whole arrangement is mounted in such a way as to allow of the beam being thrown in any direction required. A simple form of projector, as an apparatus of this kind is called, manufactured by Messrs. Scott, is shown in Fig. 68.

Arc lights are also employed to a considerable extent as signals on board large passenger steamers and yachts which have electric lighting machinery on board, as is now generally the case, most of the more important passenger steamers and the larger yachts having their saloons and cabins lighted by incandescent electric lamps.

A great many makers have designed very compact combinations of engines and dynamos intended specially for use on board ship, where space is limited, and one of these is shown in Fig. 69, which illustrates a combination manufactured by Messrs. Mather & Platt, of Manchester, consisting of a very effective and compact form of dynamo, known as the "Manchester Dynamo," driven from a double-cylinder diagonal engine, by means of a short belt provided with tightening gear, as shown in the illustration.

Another very interesting application of arc lighting to shipping purposes is afforded by the arrangements which have been adopted within the last few years for making the passage of the Suez Canal at night.

Up to the year 1885 no night traffic through the canal

was permitted, but in that year it was decided to allow vessels of war and those carrying mails, if furnished with electric lights in accordance with the regulations laid down by the canal company, to traverse at night any portion of the canal between Port Said and the Mediterranean entrance, about a third of the entire distance. The first vessel which availed itself of this permission was the steamship "Carthage," belonging to the Peninsular and Oriental Steam Navigation Company, which made the passage by the aid of the electric light with perfect success in April, 1886, and the example was followed shortly afterward by other vessels with such success that the company decided to extend the permission to all vessels, and at the same time, by providing beacons and light-buoys, to guide the vessels during the night passage, navigation by night was made possible throughout the whole canal.

The company stipulates that all vessels availing themselves of this permission should be provided with a projector search-light, fitted upon a platform large enough to accommodate a man to manipulate the light, the platform being connected to the vessel as near to the water's edge as possible, and an automatic electric lamp suspended upon the bridge, capable of illuminating an area two hundred yards in diameter round the vessel. The man on the platform regulates the position of the carbons of the search-lamp by hand, and at the same time he depresses or deflects the light to either side in accordance with the orders of the pilot upon the bridge, the orders being usually given by means of a telephone.

The placing of the projector close to the edge of the water, so that the light may be hidden under the bow of the ship, is an essential point, for any direct rays of light

intervening between the pilot and the distant illuminated object, by means of which he is steering the vessel, would dazzle his eyes. Fig. 70 shows a vessel so fitted passing through the canal.

The lamp suspended over the bridge lights up the whole deck of the vessel and the canal with its banks on either side, and is only intended for use when passing other ves-

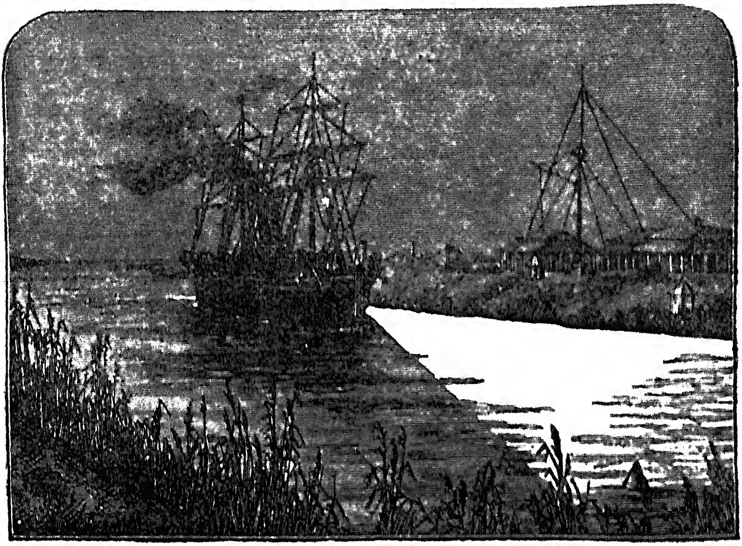


FIG. 70.

sels which are tied up at the passing-stations, or to provide light for a vessel thus tied up in order to allow another one to pass. Several of the chief coaling firms at Port Said have now provided themselves with sets of portable electric lighting plants fulfilling the requirements of the company's regulations, and any vessel which does not possess a plant of its own may hire one of these for a fee of £10.

Electric Candles.—Before passing on to describe the sys-

tem of incandescent electric lighting I must not omit to mention the Jablochkoff electric candle.

This consists of a pair of carbon rods, placed side by side, and separated by a strip of insulating material, usually consisting of a kind of porcelain. The current passes up one carbon and down the other, forming an arc at the top, and the porcelain gradually burns away with the carbons.

In order to start the arc when the current is turned on, the top of the candle is generally tipped with a paste made of powdered carbon and gum. The Jablochkoff candle is of considerable interest historically, as it was employed in lighting up the Avenue de L'Opera in Paris in 1878, which was the first example of street lighting by means of electricity. It was also employed on the Victoria Embankment in London, and in many other places.

In the case of the current being accidentally interrupted the candles will go out, and they will not reignite themselves; but a still more serious defect is that the resistance of the arc undergoes constant variation owing to impurities and variations in the density of the porcelain, so that the light is extremely unsteady.

Some modifications of Jablochkoff's original candle have been devised in order to overcome these defects, and in some cases with considerable success, but their use is not sufficiently extensive for it to be necessary for me to describe them here.

Incandescent Lighting.—Arc lamps are not at all suitable for the lighting of rooms in dwelling-houses, or for the lighting of the interiors of theatres, as the light is far too intense: what is required for such purposes is a considerable number of centres of light of moderate intensity, and not one or two centres of very high intensity, such as are given

by arc lamps. This requirement is completely fulfilled by what are known as incandescent or glow lamps, which moreover lend themselves exceedingly well to decorative purposes, much better indeed than gas-burners.

The principle of the incandescent lamp consists in passing the current through a wire or filament of some substance which is only fusible with difficulty, and which has a comparatively high electrical resistance.

The heat generated by the passage of a current through such a wire, or filament, raises it to a white heat, and provides a source of light very much whiter than ordinary gas-light, and which has many other important advantages over it. In the first place, although the filament itself is maintained at an exceedingly high temperature, a glow-lamp has much less heating effect in a room than a gas-burner, because the surface of the heated filament is exceedingly small, and it is inclosed in an exhausted glass vessel, while the gas flame is in immediate contact with the air, and soon distributes its heat over a room by means of the strong convection currents which it sets up in the air in its neighborhood.

The electric light again can be turned on or off without having to be lighted, so that the light can be turned on as one enters a room by simply pressing a button or turning a switch near the door; and if light is wanted in a bedroom at night it can be turned on, without the slightest danger, by means of a switch which can be reached from the bed.

The greatest advantage, however, of the electric light over illumination by means of gas is the complete absence of any process of combustion, so that the air in the rooms in which it is employed does not become vitiated by the absorption of oxygen, and the liberation of carbon acid

and still more deleterious compounds, such as sulphurous acid and sulphuretted hydrogen, which are always formed when gas is burned, and which gradually cause the covers of books in the library to become rotten, discolor the gilding of picture-frames, and make it impossible to keep most kinds of plants alive in rooms where gas is burned.

The first electric glow-lamp was invented by Demoleyns as far back as the year 1841, a platinum wire being employed as the filament. In 1845 carbon was first used for the purpose by Starr of Cincinnati; and in order to prevent the combustion of the carbon he placed it in a closed glass vessel, from which the air had been exhausted, as is now invariably done in all glow-lamps, whatever the material employed for the filament. These lamps, however, were invented before the development of the dynamo had made electric lighting possible on a commercial scale, and they accordingly dropped out of sight until, in the year 1873, the Russian physicist Ladiguine turned his attention to the subject, and his investigations were considered of such importance that he was presented with a prize by the St. Petersburg Academy of Sciences. The report which was drawn up for the occasion by the Russian physicist Wilde contains a very clear and succinct statement of the advantages of carbon for glow-lamp filaments. Carbon, said the report, has, at an equal temperature, a greater radiating power than platinum, while its thermal capacity is much smaller, so that the same amount of heat will raise a carbon filament to a much higher temperature than a platinum wire. Moreover the electrical resistance of carbon is about two hundred and fifty times greater than that of platinum; and the carbon may therefore be made thicker and yet rise in temperature as much as the metal. Carbon, moreover,

is infusible, and its temperature may therefore be raised without any danger of fusion.

In the year 1879 Edison constructed a lamp in which a carbon filament was employed. It was prepared by cutting small sheets of brown paper in the form of a horseshoe, placing several of these sheets together, and then heating them to a high temperature in an iron mold. The life of a lamp provided with a filament of this kind was however very short, as the carbon soon became disintegrated by the action of the current. In the year 1880 Edison improved this lamp by substituting carbonized bamboo for carbonized paper; and some improvements were introduced by Swan, who in November of the same year exhibited the first incandescent lamp shown in England to the Society of Telegraph Engineers. Swan's carbon filaments are made of strings of cotton about four inches long, having their ends enlarged by winding additional cotton round them. These threads are soaked for some time in a mixture of sulphuric acid and water, which causes them to assume the hardness and compactness of parchment. The filaments are then thoroughly washed, so as to remove every trace of acid; after which they are passed through dies with circular holes in them, in order to reduce them to a uniform cross section. The filaments are then wound upon rods of carbon or earthenware, so as to give them the required form before carbonization. They are carbonized by burying them in powdered charcoal contained in a crucible, and raising them to a very high temperature in a furnace for a period of several hours. The filaments are mounted by having their thick ends inserted into split metal tubes, which are made to clasp them tightly by means of sliding rings, the arrangement being exactly similar to a port-crayon. Plati-

num wires are attached to the upper ends of the metal tubes, and pass out through the glass.

Edison's lamps, as improved by Swan, are now very generally employed, being manufactured by the Edison and Swan United Electric Light Company, which was formed for working the patents of these two inventors. The first stage in the manufacture of an Edison-Swan incandescent lamp consists in attaching the prepared filament to its platinum wires, and mounting it upon a glass bridge, little beads

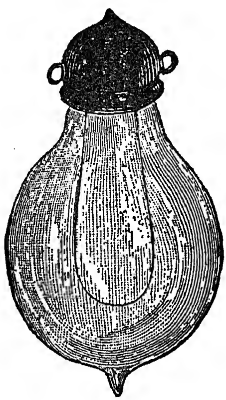


FIG. 71.

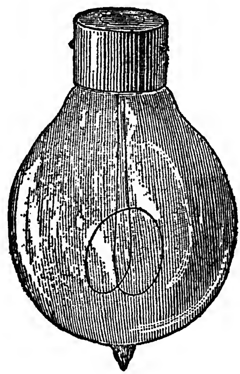


FIG. 72.

of glass being formed at the same time on the wires where they are to pass through the walls of the lamp. The glass globe is then blown very much in the shape of a pear, the glass tube out of which it is blown taking the place of the stem of the pear. The lower portion of the tube is then cut off with a file, and the carbon, with its platinum wires, fused into the upper half, after which the two portions of the globe are joined together by the blow-pipe.

The lamp is then exhausted of air, first by means of an ordinary air pump, and finally by means of a Sprengel mer-

cury pump, with which a very high vacuum can be obtained. Before the lamp is removed from the Sprengel pump it is submitted to a process known as flashing.

This consists in raising the filament to incandescence by passing an electric current through it, which expels any gas that has been absorbed by the carbon, and at the same time increases its density. The filament is usually raised to incandescence and then allowed to cool, several times in succession, the process of exhaustion going on all the time, so as to remove all the gases that are given out by the filament.

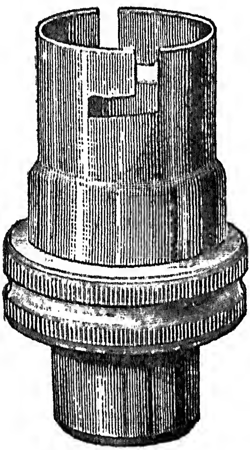


Fig. 73.

The general appearance of the lamps when completed is shown in Figs. 71 and 72, Fig. 71 showing a lamp which is intended to be hung with the larger end downward by inserting into the two loops, attached to the cap which forms the termination of the small end, the ends of the conducting wires, which are bent into the form of hooks for the purpose; while Fig. 72 shows another lamp having a filament of somewhat different shape, and which is intended to be inserted in a holder such as that shown in Fig. 73.

Theatre Lighting.—The system of incandescent electric lighting presents special advantages for the lighting of theatres, the most important of which is the almost absolute safety which it provides against danger from fire, when the installation is properly carried out.

Whether gas or electricity be employed, the lighting of the auditorium can be carried out just as safely as that

of an ordinary house, but the illumination of the stage is a very different matter.

To begin with the part visible to the audience: the footlights, when gas is used, are simply naked gas-lights, and numerous accidents have occurred from the dresses of actresses catching fire from their approaching too near to these naked lights. When the electric light is employed the footlights are all hermetically sealed glass globes, which could not ignite the most flimsy material, unless it were left in contact with them for a considerable time. The principal source of danger, however, is to be found, not in the footlights, and the permanent stage lamps which are attached to battens suspended from the roof, but in the movable lights which are attached to the different portions of the scenery, being fixed to what are sometimes called stage-ladders, which are hung on to the movable scenery wherever they are required. Any one who has been behind the scenes of a theatre, and has observed the close proximity of these lights to the inflammable scenery, will only wonder that fires are not of more frequent occurrence in theatres where gas is employed. When incandescent lamps are used instead of gas-lights, this danger is entirely obviated, provided the most elementary precautions are taken, for the electric lamps will not ignite even paper or muslin merely brought into momentary contact with them, though such materials would take fire in the course of time if they were wrapped round the lamps, or allowed to rest upon them while incandescent.

It is of course necessary in carrying out an electric light installation in a theatre, as in a private house or elsewhere, that the work should be done in a proper manner, and by men who understand their business; for if the work were

carelessly done, heating might take place, owing to bad contacts; or if the positive and negative mains were brought too close together at any point, an arc might be formed across them. A good many fires were caused in this way in some of the earlier installations; for before people had become generally alive to the fact that a badly carried out installation might be a source of very serious danger in this direction, unskilled workmen were allowed to carry out the work without proper supervision. As regards the comfort of the audience, the electric light also possesses a very great advantage over illumination by gas, on account of its comparatively small heating effect.

Any of my readers will be able to test this for themselves, if they have not already done so, by comparing the atmosphere toward the end of the performance at an electrically lighted theatre with that of a theatre lighted by gas.

The electric light also lends itself much more readily than gas to scenic effects, as by the introduction of suitable resistances, either directly into the lighting circuit, or into the exciting circuit of the dynamo, the intensity of the light may be varied by imperceptible steps from full brilliancy to complete extinction.

The first of the London theatres which was lighted by electricity was the Savoy, which was then, as now, under the direction of M. D'Oyley Carte, and special credit is due to him for his enterprise in introducing the light, as this was the first time that an incandescent electric lighting installation was carried out upon any considerable scale.

The work was done by Messrs. Siemens in the year 1881, and the lighting, which has remained under their charge ever since, has been thoroughly satisfactory in every way from the time it was first introduced. Since then the system

of incandescent lighting has been introduced into a good many other theatres—the Criterion, the Prince of Wales's, Terry's Theatre, the Adelphi, and the recently-built Lyric and Shaftsbury Theatres being now lighted by incandescent electric lamps.

In all modern installations of the electric light in the interior of buildings, safety-fuses are inserted wherever a branch wire leaves the mains, and in some cases they are attached to each lamp, or group of lamps. They consist

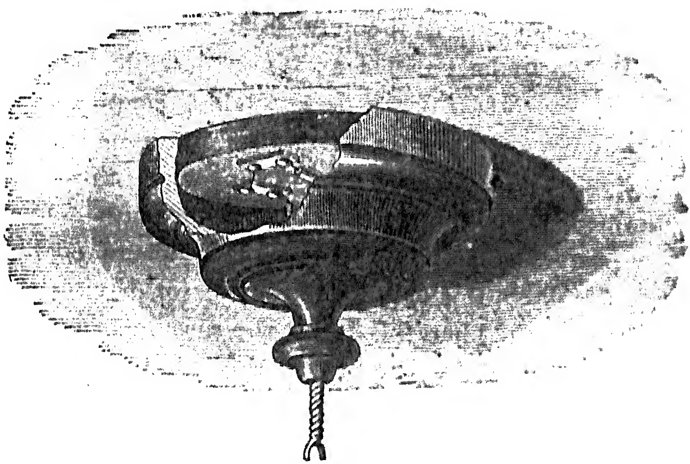


FIG. 74.

simply of a short wire which will fuse before the current has become great enough to cause danger to the lamp, and will thus cut the lamp, or group of lamps, out of the circuit. Similar safety-fuses are placed wherever an increase of the current beyond a certain amount would be likely to cause danger of fire, and large magnetic cut-outs are often attached to the mains as they leave the dynamos, and adjusted so that they will cut off the current as soon as it rises beyond a fixed maximum value. Fig. 74 illustrates a safety-fuse,

and the manner of attaching it to a lamp, or group of lamps, suspended from the ceiling in the room of a house.

Private Installations.—As the number of central stations increases, private installations, as far as the larger towns are concerned, will probably become gradually rarer; but their use will most likely extend still more than it has already done for the purpose of lighting isolated country houses, in place of employing private gas plants, the presence of which in the neighborhood of a house is exceedingly objectionable, owing to the injurious and foul-smelling gases contained in coal-gas as it comes from the retorts, and from which it has to be purified as far as possible before it is used. Where water-power is available, electric lighting, independently of its other advantages, is the most economical system which can be adopted, but where this is not to be obtained, a gas engine is probably the most convenient motive-power to employ. In a place where coal gas is already available this may be employed for driving the gas engine, but even when this is not the case a gas engine may still be employed, for engines of this kind are now made which manufacture their own gas from petroleum.

Fig. 75 shows the arrangement of a small private installation of this kind carried out on the accumulator system; the dynamo being driven by a gas engine. The lamps are connected across the negative and positive mains, as shown in Fig. 76, which illustrates the general arrangement of the connections in a private installation in which accumulators are employed. The switches used for turning the dynamo current directly on to the house leads, and for connecting these and the dynamo with the accumulators, are usually, for the sake of convenience, fixed on a single board, as shown in the illustration. When the current from the ac-

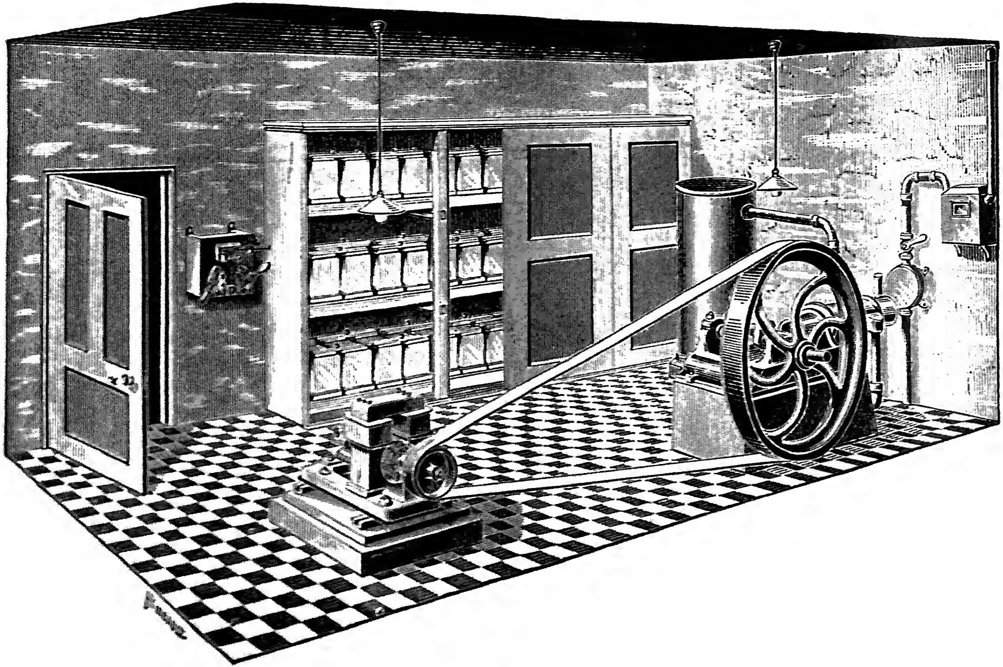


Fig. 75

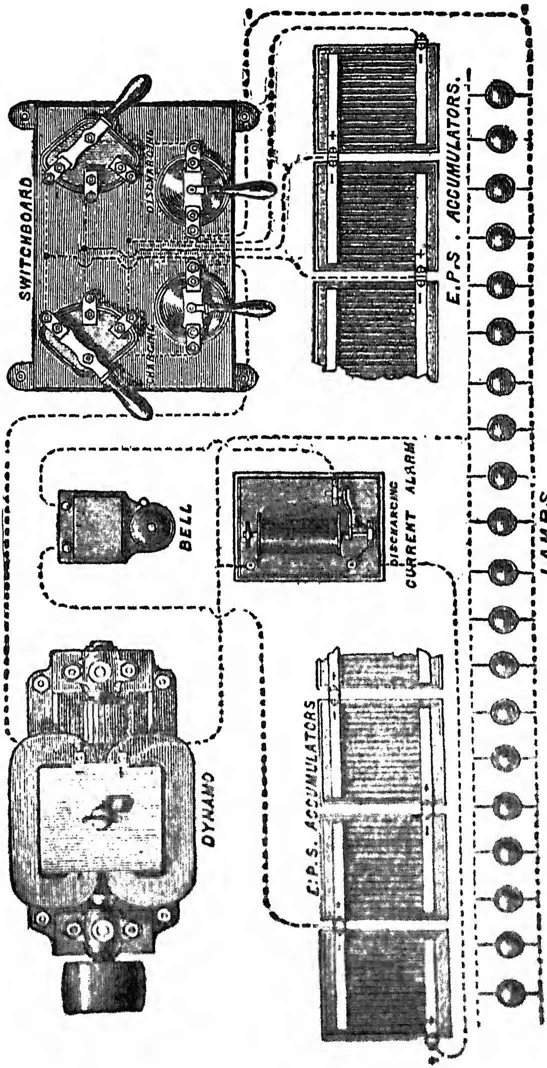

SWITCHBOARD
DISCHARGING
CHARGING
E.P.S. ACCUMULATORS.
BELL
DISCHARGING CURRENT ALARM
DYNAMO
E.P.S. ACCUMULATORS
LAMPS

Fig. 76.

cumulators is in use, they must not be allowed to discharge at more than a certain rate, as if this were exceeded they would be damaged. In order to prevent this from taking place unperceived, an automatic current-alarm, connected with a bell, is employed, as shown in the centre of the illustration. The current-alarm consists of a coil of wire, with a soft-iron core suspended in its centre, and kept in position by means of a spring. As the strength of the current increases, the iron is drawn further into the coil, until, when a certain point is reached, the bell is started and continues ringing until the discharge current is lowered to the proper amount.

Accumulators are almost invariably employed in private installations, for if they were not used the engine would always have to be kept running as long as the light was required, while, when they are employed, they can usually be charged sufficiently to supply all the current required, by running the engine two or three days a week. It would be impossible, moreover, to get a satisfactory light without the use of accumulators from a dynamo driven by any form of gas engine at present in use, as these engines cannot be made to run with the same regularity as steam engines, and the result would be that the light would fluctuate at every revolution of the engine, which would of course be exceedingly disagreeable.

Train Lighting.—Another very useful application of accumulators is to the electric lighting of trains, which has been carried out with the greatest success during the last few years on the Great Northern, and the London, Brighton and South Coast Railways.

The accumulators are made by the Electrical Power Storage Company, and are of the same character as the

one previously described, except that the cells are made of such a shape as to permit of their being conveniently stowed away in boxes under the seats of the carriages.

The South Eastern Railway Company also has quite recently fitted electric reading-lamps to the carriages on the main-line trains. The lamps, which are of five-candle power, are contained in small boxes placed just under the racks.

The light is obtained by introducing a penny into a slot at the top of one of these boxes, and then pressing a knob, and it will last for half an hour, at the end of which time it extinguishes itself automatically. The light can be obtained for as long a time as is required by placing a penny in the box every half hour, and it can be extinguished at any moment by pressing a second button.

If the instrument is out of order, or if a coin other than a penny is put into the slot, the coin drops right through, and can be recovered.

Portable Electric Lamps.—It is evident that the introduction of incandescent electric lamps would be of the greatest value for the use of divers, as, owing to there being no combustion, a supply of air is not required; and also for use in coal-mines containing explosive gases. In such cases as these it would not always be convenient to have the lamps attached to long wires leading to the source of current. Primary batteries might, of course, be used, and indeed they have been used, for portable lamps; but, in addition to the expense involved in their being lighted in this way, a primary battery, to give a light for any length of time, would be too bulky to be conveniently carried about. Both these defects are got over by the use of accumulators, and a portable lamp of this kind, manufactured by the Edison-

Swan United Electric Light Company, is shown in Fig. 77. The lamp is energized by a four-cell accumulator, shown in Fig. 78.

This accumulator is contained in a strong teak box, A, Fig. 77, strengthened with metal bands, BB. A small incandescent lamp is attached to the side of the case, and protected by a strong glass cover, C, with a cross-bar, G, and a hinged lever secured by a safety-nut, F, and provided

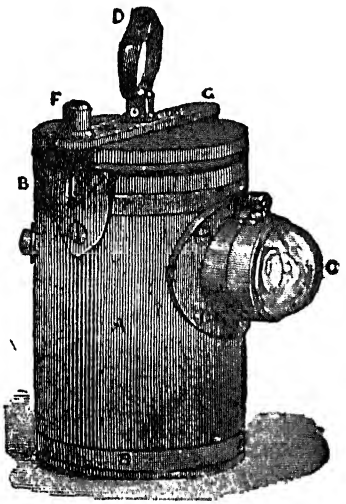


Fig. 77.

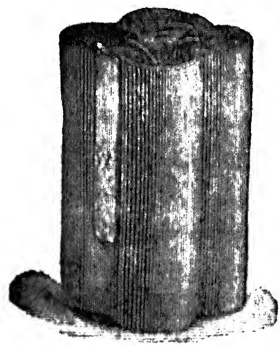


Fig. 78.

with a swivel handle, D. The lamp can only be opened by means of a key, so that it cannot be got at by the miners. In some lamps of this kind which have recently been constructed, a small lever is provided which maintains the continuity of the circuit as long as it is pressed down by the glass cover, C, but breaks the circuit when allowed to rise, which it would at once do if the outer glass cover were accidentally broken. The object of this arrangement

is to prevent a miner from continuing to use a lamp of which the outer covering has been broken, as if this were done the glass globe of the lamp, being of very much thinner glass than the outer covering, would be very likely to get broken, and although the lamp would be extinguished almost immediately by the fibre burning away, there might be just time for it to ignite the explosive gas in the mine.

CHAPTER XVI

ELECTRO-MOTORS AND THEIR USES

An electro-motor is really nothing but a dynamo working backward—that is to say, one which, instead of being driven by the application of external power, and thereby transforming the energy supplied by a steam engine or other prime motor into the form of electrical

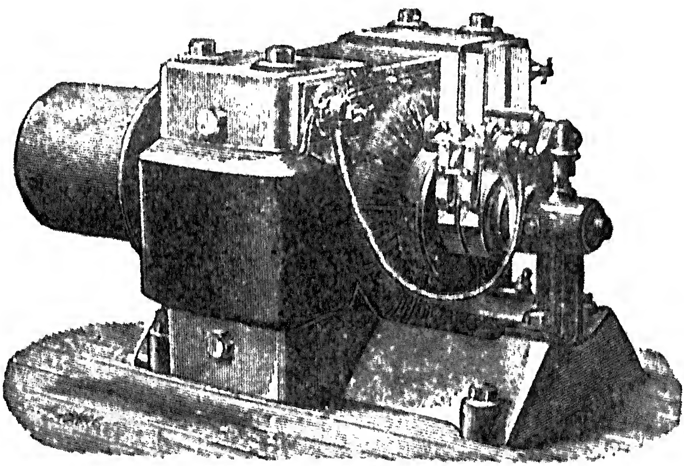


FIG. 79.

energy, is supplied with electrical energy by means of an electric current, which sets the motor in motion, and transforms the electrical energy into mechanical energy. Fig. 79 illustrates a motor made by Messrs. Immisch & Co., one of the few firms which have devoted themselves to the con-

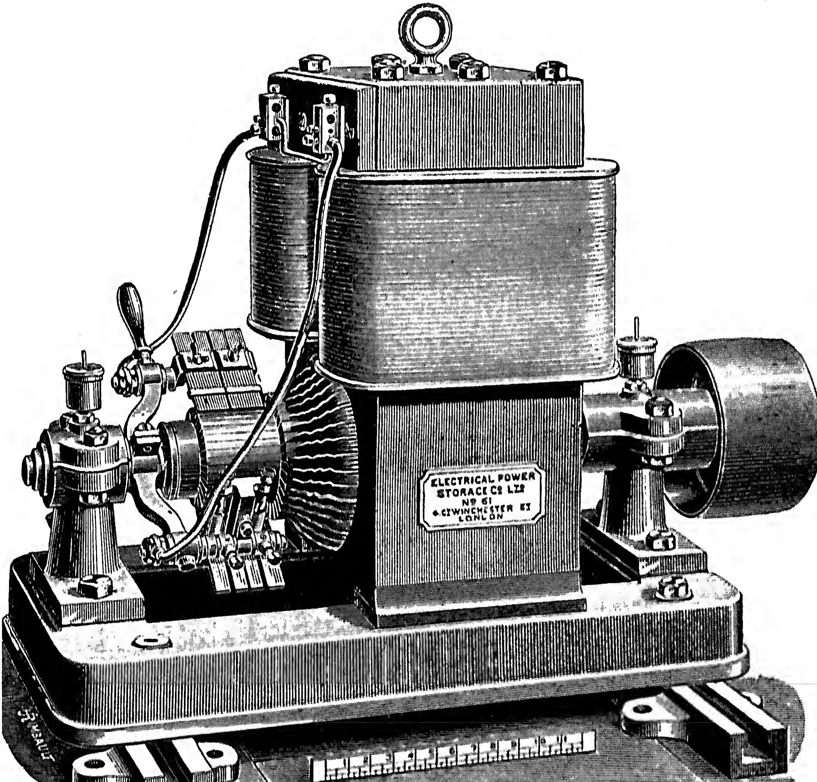


FIG. 80

struction and improvement of the electro-motor, and whose motors have already obtained a world-wide reputation for high efficiency and good workmanship.

Another type of motor, manufactured by the Electrical Power Storage Company, is shown in Fig. 80.

The reversibility of the dynamo, enabling it to act as a motor when supplied with electric current, was first made known by M. Hippolyte Fontaine at the Vienna International Exhibition of 1873. According to M. Figuier, the discovery was purely accidental.

Figuier's account is that the Gramme Company had two machines exhibited at the Exhibition, and one day while one of these machines was in motion, and the other one was standing still, a workman, seeing some cable ends lying loose upon the floor, fancied that they belonged to the machine at rest, and placed them in its terminals, when, to the astonishment of everybody, the armature of the machine began to rotate, being driven by the current from the other machine. Prior to this a great many attempts had been made to construct electric engines, or motors set in motion by means of an electric current, but none of them was of any practical use, and they were, in fact, nothing more than scientific toys. Any continuous current dynamo can be used as an electro-motor; but in the construction of electro-motors it is much more important to make the weight as small as possible than in the case of dynamos; and there are some other points which are of greater practical importance in the case of electro-motors than in the case of dynamos, so that, although the principles of construction are the same in each case, it is not very often that machines constructed for producing current are actually employed as electro-motors.

Electric Railways.—One exceedingly important application of the electro-motor is its employment for the purpose of traction. For some time past, experiments have been in progress with the view of adopting electric traction on the underground railways in London, in order to get rid of the contamination of the atmosphere by the smoke and other products of combustion from the locomotives, which now make the line so unpleasant to travel upon. Electric traction, however, has not yet been practically employed for heavy railways, though it has been used to a considerable extent for light railways, or, as we call them in this country, tramways.

The electric propulsion of cars on tramway lines can be effected in two distinct ways. One is to place accumulators on the car, these accumulators being charged at fixed stations, usually at one or both of the termini. The principal disadvantage of the accumulator system is the great weight of the accumulators, which have of course to be carried by the cars; and it also has the disadvantage of the additional loss incurred in two transformations of energy, as in the accumulator system the energy of the prime motor must first be transformed into electrical energy, and then into chemical energy, which is stored up in the battery, from which it is reproduced in the form of electrical energy, and then again converted into mechanical energy in the motor. The advantages are that each car is independent of every other, and that no fixed conductors are required along the line.

The accumulators used in driving cars on this system are, as in the case of train-lighting, stored under the seats, and in any case the electro-motors are usually placed under the floor of the car.

The other method of driving cars electrically is to em-

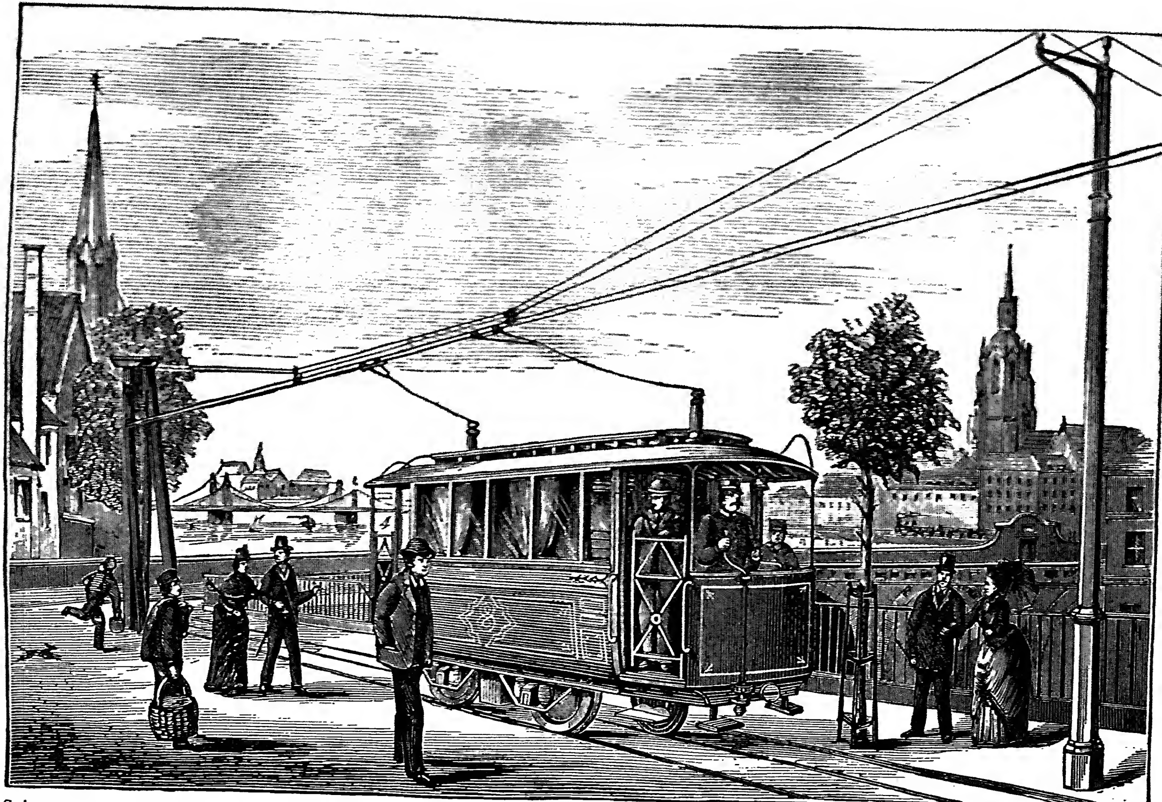


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FIG. 81

ploy a fixed source of energy, and to transmit the curre to the car by means of a conductor and sliding contac Mr. Gisbert Kapp, in his work on the "Electrical Tran mission of Energy," classifies the electric railways work on the conductor system into four divisions, according the manner in which the current is conveyed to and from t car. In the first class the rails are insulated from the groun and the separate rails being placed in electrical communic tion by means of connecting pieces, they are employed conductors, one conveying the outflowing and the other t return current. The car-wheels in this system have to insulated from their axles.

A short tramway of this kind has been erected by M Volk on the beach at Brighton, and another one is in u in Berlin.

The second class consists of those in which a separa conductor is used for the outflowing current, while the r turn current is carried by both rails. The rails need n be insulated, but must be in electrical communicati throughout by means of special connecting pieces at t joints. The Bessborough and Newry Electric Railway a good example of this class; it is three miles in lengt and the electric current is supplied by two Edison-Hopki son dynamos driven by a large turbine placed at a stati at about the middle of the line, where ample water-pow is available.

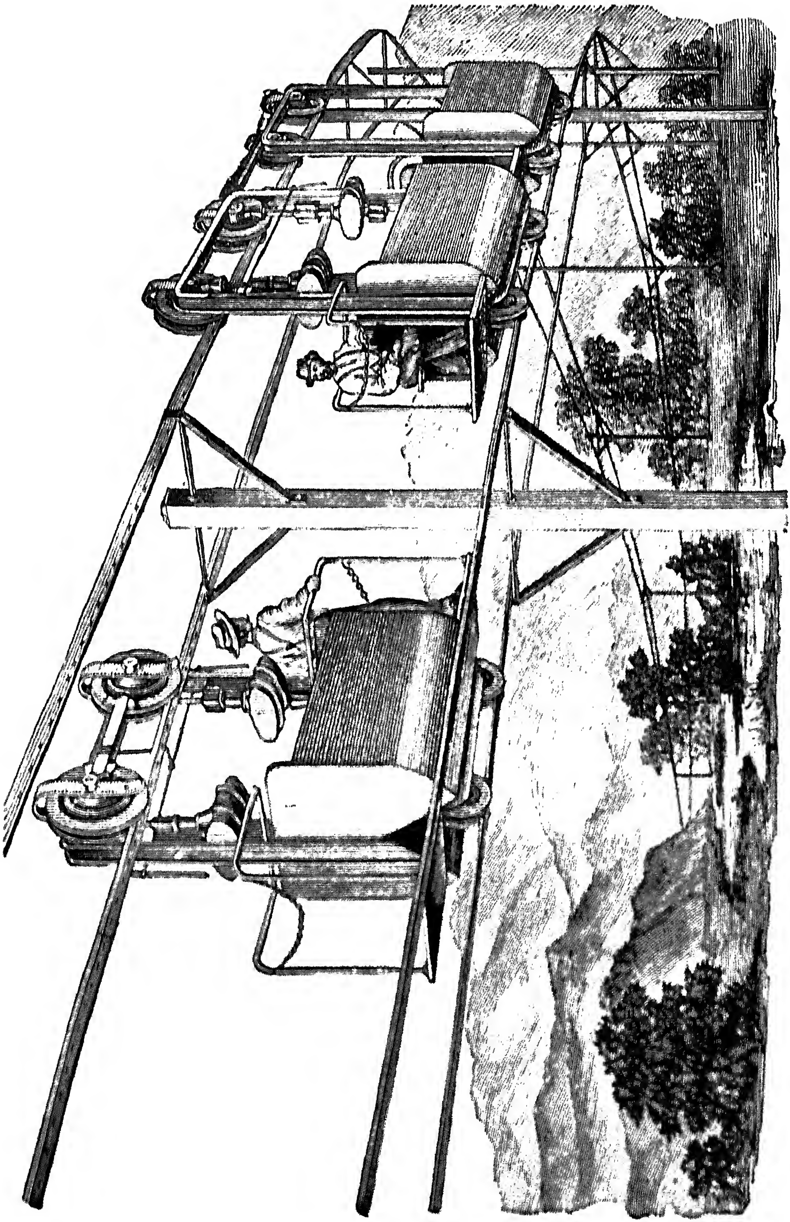
Other examples of this kind are given by the railwa at Portrush and Blackpool.

In the third class separate conductors are used for t outflowing and the return current. These are carried ove head on poles, and usually consist of iron or copper tube A line of this kind is now in use between Frankfort a

Offenbach on the Maine. A portion of it is shown in Fig. 81. The conductors consist of tubes of wrought-iron, of one inch internal diameter, and one and one-fifth inches external diameter, suspended, by means of iron wire ropes, from ordinary telegraph poles. A slot is cut out along the whole length of each tube, and the current is conveyed to and from the car by means of wires attached to small cylinders of cast-iron, which slide within the tubes. The same system is in use in Berlin, Vienna, and other places.

In the fourth class separate conductors are used for the outflowing and return current, and these are attached to poles, and arranged so as to form a single line on which suspended trucks run. This is known as the telepherage system, and was devised by Professors Ayrton, Perry, and Fleeming Jenkin for carrying light loads over hilly or mountainous country. The first line of this kind was constructed at Glynde, in Sussex, and has been a complete success. Fig. 82 shows a similar line which has been constructed in America by the Sprague Electric Railway and Motor Company, for the purpose of carrying ore from a mine on a mountain side to a railway at the base. The road, or overhead track, consists of two stationary steel cables, suspended one above the other, between posts of wood or metal, fifty feet or more apart, and at such a height from the ground as not to interfere with the surface traffic. The cars run on wheels, and are suspended between the upper and lower cables, the upper cables carrying most of the weight. Each car contains an electro-motor, which is supplied with current by contact of the wheels with the cables.

Several attempts have been made to apply electricity to ordinary street locomotion. One of the first of these was an electric tricycle designed by Professors Ayrton and Perry.



Some dog-carts driven by electricity have also recently been constructed by Messrs. Immisch & Co. One of these was made for the Sultan of Turkey in September, 1888, and he appears to have been so pleased with it that he has ordered another one to be sent out. This is of an improved pattern, and is shown in Fig. 83. The power is stored in twenty-four small accumulators, which weigh about seven hundredweight, and contain a charge sufficient to propel the vehicle at a speed of ten miles an hour for about five hours. The cart is driven by a one-horse power Immisch motor. The total weight of the carriage and accumulators is about eleven hundredweight.

These carts are only suitable for use on the level, and on good roads, as the wheels have not got sufficient grip to carry the cart up any considerable incline, and this is one of the chief difficulties in propelling any carriages, other than extremely heavy ones, such as traction engines, either by electricity or by steam power.

An electric omnibus has also recently been tried in London, but I believe it was only run at night, which was certainly a most desirable precaution, as, owing to the weight of the accumulators, electrically propelled vehicles are difficult to stop suddenly, and on one occasion when it was being run at night in Oxford Street, a hansom cab dashed out of a side street in front of it, and the driver, unable to stop in time, stated afterward that there were three alternatives open to him—viz., either to run into the lamp-post, the hansom, or the nearest house. He chose the former, breaking the lamp-post off near the ground, and planting the car on the top of it. The passengers inside were of course covered with the acids from the cells, and one of them foolishly striking a light, ignited the gas from

the broken lamp-post, so that had they not shortly been released from their perilous position they would all have been burned.

Another interesting example of the use of the electro-motor for the purpose of traction is its application, as far back as 1879, to plowing fields in the neighborhood of the beetroot factory at Sermaize. The manufacture of beet sugar is only carried on during a small portion of the year, so that for the rest of the time the machinery remains idle, and it occurred to the proprietors that it would be advantageous to use the steam engine during this slack time for plowing the fields in the neighborhood. The experiment was perfectly successful. The current was generated at the factory by means of a Gramme dynamo driven by the steam engine, and the plowing arrangement was similar to that adopted in steam plowing, the plow being drawn backward and forward across the field by a steel wire rope coiled and uncoiled alternately from drums carried on trolleys placed at opposite sides of the field, and each provided with a Gramme dynamo used as a motor.

Electric Launches.—The electrical method of propulsion is extremely well suited for small launches, in the place of steam, and a large number are now in use. Fig. 84 shows the general appearance of an electric launch as manufactured by the Electrical Power Storage Company. The sectional diagram, Fig. 85, shows the position of the motor under the deck of the launch, and of the accumulators, which are shown extending from the motor to near the bow of the vessel. The great advantages of this method of propulsion are the complete absence of smoke and dirt, and the increased room, owing to the whole of the machinery being placed below the deck. The chief difficulty attending the

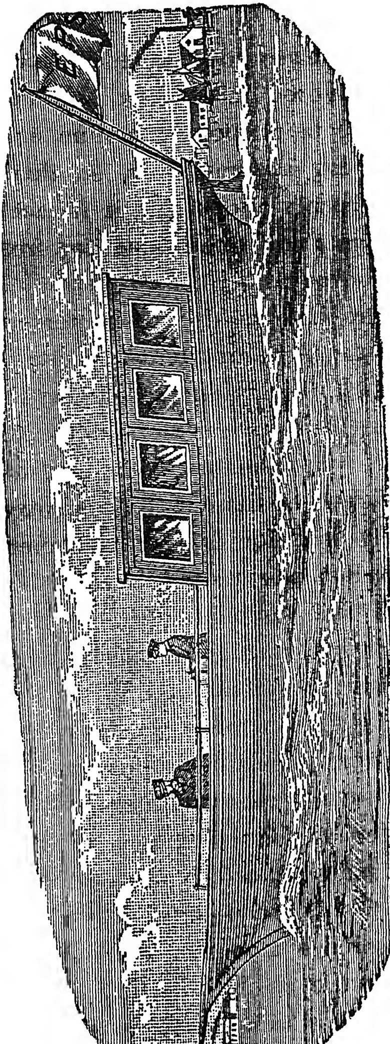


FIG. 84.

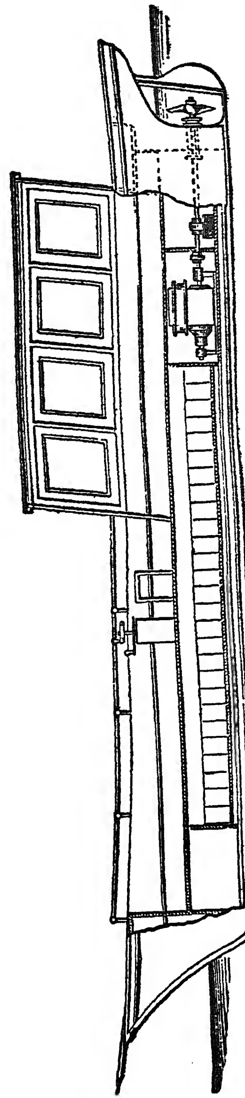


FIG. 85.

use of the electro-motors for propelling steam launches is that they cannot run to any great distance from the charging station.

Messrs. Immisch & Co., who have constructed a number of these launches, have endeavored to remedy this want on the river Thames by the construction of a number of stations at intervals for charging accumulators, so that a launch on arriving at one of these stations can, if its accumulators have run down, have them exchanged for fresh ones and proceed upon its journey.

Other Applications of Electro-Motors.—Electro-motors are now coming into extensive use in mountainous countries, as, for example, in Switzerland, for driving machinery by means of water-power, at distances which sometimes extend to several miles. In America, where electric lighting from central stations is much more general than in this country, electro-motors are very largely used for driving machinery in small workshops, where the power required would not be sufficient to make it worth while to use a steam engine. These motors are used for driving printing presses, tailors' and shoemakers' sewing machines, watchmakers' lathes, and similar apparatus; and there is no doubt that, as the system of supplying electric current from central stations extends in London and other English towns, electro-motors will be more and more employed for similar purposes in this country. One of the great advantages of the electro-motor for purposes such as these is that it can be fixed just where it is required, and used to drive a machine, without the intervention of belts, driving pulleys, and shafting. This is very well illustrated in Fig. 86, which shows an electro-motor driving one of the fans now so extensively used for ventilating ships, factories, mines, etc. For driving venti-

lators and other machinery in mines the electro-motor is especially valuable, as it does away with the driving rods and other moving gear, which has always been a source of trouble in the shaft of a mine, replacing it by a simple

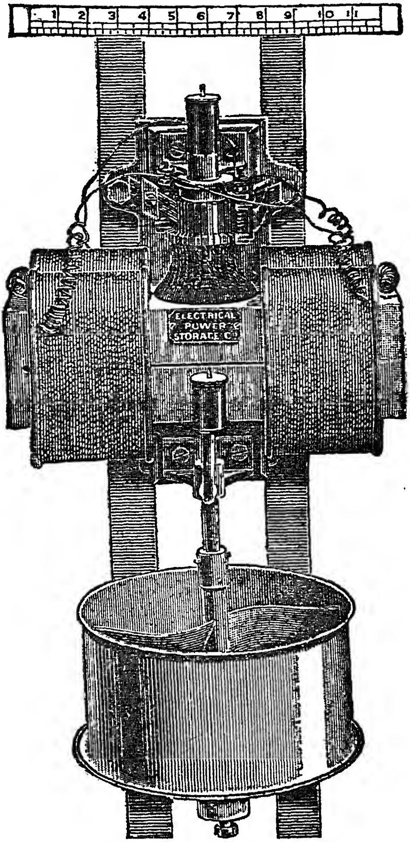


FIG. 86.

fixed cable. With regard to the applications of electro-motors for use in private houses, where the electric current is supplied from central stations for lighting purposes, such of my readers as may be amateur mechanics will easily per-

ceive what an advantage it would be to be able to drive their lathes or other machinery by means of a small motor

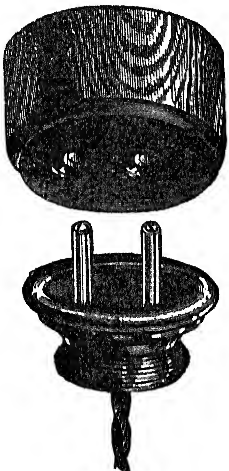


Fig. 87.

which could be set in action in a moment by simply inserting a pair of contact plugs into a *shoe*, as it is called, fixed at any convenient part of the room. Fig. 87 shows a *shoe* suitable for this purpose, or for use with an electric reading-lamp. Some of my lady readers would probably be glad to work their sewing machines in a similar manner, by means of a motor which can be fixed directly under the table which supports the machine, and which will occupy considerably less space than the treadle arrangement generally employed.

CHAPTER XVII

ELECTRO-METALLURGY

I PROPOSE to consider under this head the electrical deposition of metals, or, as it is now called, electro-plating, and the application of electricity to the purification of metals and the reduction of metallic ores, together with the recently-invented process of electric welding.

One of the first experiments tried by every schoolboy who has been allowed to amuse himself in his holidays by constructing and experimenting with galvanic batteries, is to copy medals or coins by taking models of them in some such substance as plaster of Paris, then making the surface of the model a conductor of electricity by rubbing it over with black-lead, and finally electro-plating it with copper, by attaching it, by means of a wire, to the negative pole of a battery, and suspending it in a vessel containing a solution of sulphate of copper in which is suspended a plate of copper, connected by means of a wire to the positive pole of the battery.

In the year 1801 Wollaston discovered that if a piece of silver in connection with a more positive metal were immersed in a solution of copper, the silver became coated over with a layer of copper sufficiently coherent to stand the operation of burnishing. Two years later Cruickshank

observed that when a current from a galvanic battery was passed, by means of silver wires, through solutions of various salts of lead, copper, and silver, the metals attached themselves to the wire connected to the zinc end of the battery; and in the year 1805 Brugnatelli made the first practical application of electro-plating of which we have any record by gilding two silver medals, by attaching them to the negative pole of a battery, and suspending them in a saturated solution of a salt of gold.

Electro-plating, as a practical art, may however be considered as deriving its origin from the work of Professor Jacobi of St. Petersburg, and of T. Spencer of Liverpool, in the year 1839. Jacobi's galvano-plastic process, as he called it, enabled him to convert any line, however fine, of an engraving on copper, into a relief, by an electroplating process which he describes as being applicable to copper-plate engraving, copying medals, producing stereotype plates, copper-plating plaster ornaments, and the manufacture of calico printing blocks and patterns for paper hangings.

The first patents in this country and in France were taken out by Messrs. Elkington, of Birmingham, who still occupy the foremost position in the electro-plating industry in this country.

The earlier electro-plating work was of course carried out by means of primary batteries; but these are no longer used for the purpose, except for operations on a very small scale—such, for example, as those of the schoolboy to whom I have referred—and the electric current required for the purpose is now always obtained from dynamos. The dynamos employed for the transmission of electric energy and for producing electric lighting currents would be quite un-

suitable for use in electro-plating, for the quantity of metal deposited in the bath depends only on the strength of the current, and not upon its electro-motive force, so that it is only necessary to obtain an electro-motive force sufficient to drive the current through the bath of liquid in which the objects to be plated are immersed. An electro-motive force of four or five volts is usually amply sufficient for this purpose; and if it is much higher than is required, not only is there a useless waste of energy, but it is found that the metallic deposits become uneven and wanting in coherence.

The dynamos to supply current for electro-plating must therefore give a large current at low pressure, and therefore they must have a very small internal resistance, which means that the coils must be made of thick wire, and therefore comparatively short. Continuous current dynamos are of course the only ones that can be employed for electro-plating, and the method of exciting them must be such that there is no danger of the current becoming reversed, as the result of this would be to remove the metal which had already been deposited upon the object to be plated.

One of the most important and best known electro-plating operations consists in the deposition of gold and silver on various less expensive metals. Another important application, which is rapidly becoming a great industry, consists in covering readily oxidizable metals like iron with a thin layer of a more durable material, such as nickel. This process is largely employed for trappings of harness, the ironwork of carriages and cycles, and also for many articles of ordinary daily use.

The electro deposition of iron, first carried out by Jacobi and Klein, has recently found an important application at the hands of Professor Roberts-Austin, who employed it for

obtaining the dies for striking the medals issued on the occasion of the Queen's Jubilee. The medals were originally modelled in plaster, and the casts reproduced by the electro deposition of copper; and finally these copper dies were plated with coherent layers of iron, nearly a tenth of an inch in thickness, and hard enough to be used for stamping. The greatest drawback to this very interesting process is that the operation of obtaining a layer of this kind, sufficiently hard to be used for stamping, occupies from three to five weeks.

In Chapter X. I alluded to the fact that copper wire of great tensile strength and very low electrical resistance is now being produced at a lower price than used formerly to be paid for ordinary commercial copper. This is effected by means of a process designed by Mr. Elmore, and which is now being carried out at a factory erected for the purpose at Cockermouth.

The process, which is not only applicable to the production of telegraph wires, but also to the manufacture of copper steam-pipes, suitable for boilers and other purposes, of great strength and homogeneity, is known as the *electro burnishing process*, and consists in the electro deposition of copper upon a mandril immersed in the copper bath, and maintained in continuous rotation.

The copper as it is deposited is compressed into a firm homogeneous mass by means of a burnisher, which always presses against the mandril, and traverses continually up and down it as the latter rotates.

Tubes of a very large size can be made directly in this manner, and in order to obtain a telegraph wire from one of these tubes a helical cut is made, by means of machinery specially constructed for the purpose, starting from one end

of the cylinder and passing round it in a helix until it reaches the bottom. A helical strip of copper of square section is thus obtained, and this is drawn through a series of circular holes gradually diminishing in size, cut in steel plates, until the strip has been drawn out into wire of the required gauge. The latter part of the operation is exactly similar to the ordinary process of wire-drawing.

In the year 1871 Elkington first proposed to precipitate copper electrolytically from the fused sulphate of copper and iron which the copper-smelter designates by the term *regulus*. Thin copper plates were arranged to receive the copper as it was deposited, while the other metals present, including gold and silver, fell to the bottom of the solution.

Electricity has also been largely employed for obtaining pure copper from the impure form known as "blister copper" or "blade copper," the impure metal being attached to the positive terminal of the dynamo, and immersed in a bath of sulphate of copper, while the pure metal is deposited on a thin strip of copper attached to the negative terminal of the dynamo. This process is now so extensively used that large dynamos have been specially constructed, which, with an expenditure of 100 horse-power, will produce eighteen tons of pure copper per week.

It was suggested by the late Sir William Siemens that the exceedingly high temperature of the electric arc might be advantageously utilized in the fusion of metals with high melting points, and he actually constructed an electrical furnace in which ninety-six ounces of platinum could be melted in ten minutes.

His experiments were unfortunately interrupted by his untimely death, but the method has been recently developed and carried out on a very large scale by Messrs. Cowles, for

the purpose of isolating aluminium from corun um, and alloying it immediately with copper or iron, in order to produce the aluminium alloys which are now so extensively employed for various purposes. The adaptability of the electric arc for the production of aluminium alloys was, like many other important discoveries, made accidentally, while the inventors were engaged upon a research directed to a totally different object. It appears that the two brothers, E. H. & A. H. Cowles, went over to South America some time ago to develop a zinc mine in which their father had invested a considerable amount of capital. The ore was found to be extremely rich, not only in zinc, but also in silver; it was, however, so refractory that it could not be reduced in the furnaces which were available.

Some of the ore was then sent to Ohio to be reduced in a more powerful furnace, but even this failed to reduce it; and it therefore appeared at first sight as if the mine would have to be abandoned, but, fortunately, one of the brothers was an electrician and the other a chemist, and the former suggested that the high temperature of the electric arc might possibly be turned to account to extricate them from their difficulty.

They immediately set to work experimenting with the object of testing this suggestion. In their first experiments they filled a pipe of fire-clay with a mixture of the crushed ore and charcoal powder, placed a bunch of electric light carbons at each end of it to act as electrodes, and closed up the ends. A current from a small dynamo was then sent through the pipe, and after a short time the ore was found to be reduced, but the pipe also was partly melted, which was a very undesirable result.

The melting of the pipe was soon found to be due to the fact that the charcoal powder, which in its original form was a bad conductor of electricity, was converted by the high temperature into graphite, which is a fairly good conductor. The difficulty was overcome at the suggestion of the chemist, Mr. A. H. Cowles, by the very simple method of soaking the charcoal powder in lime water, and drying it before use.

The coating of lime thus obtained prevented electric conduction between the neighboring particles of the charcoal, and thus enabled it to retain its insulating properties, even when a portion of it had been converted into graphite. The inventors very soon recognized that this furnace was exactly what was required for the reduction of the oxides of aluminium, and experiments, which were perfectly successful, were very soon made upon corundum as the raw material. At the works which have now been erected, a current of 5,000 ampères is supplied at an electro-motive force of sixty volts, by means of a single dynamo of immense size, probably the largest which has ever been made.

The heating power of large currents has also been utilized by Elihu Thomson in the United States, and by Bernardo in Russia, for the purpose of welding metals. The Thomson process, which is chiefly employed for uniting wires and other pieces of metal of comparatively small cross section, consists in simply pressing together the two pieces to be united, while a large current is passing, when the heat developed at the junction is found to be sufficient to soften even refractory metals so much that they can be easily united. Brazing can also be successfully effected by putting brass on the joint while the current is passing. In a paper read before the American Society of Arts in 1886 Thomson suggested that the method would be of great

value for making the long lengths of pipes for boiler coils, for making endless bands for saws, wheel tires, and iron and steel links for chains; and he also considered that there would be a wide scope for the process in the repair

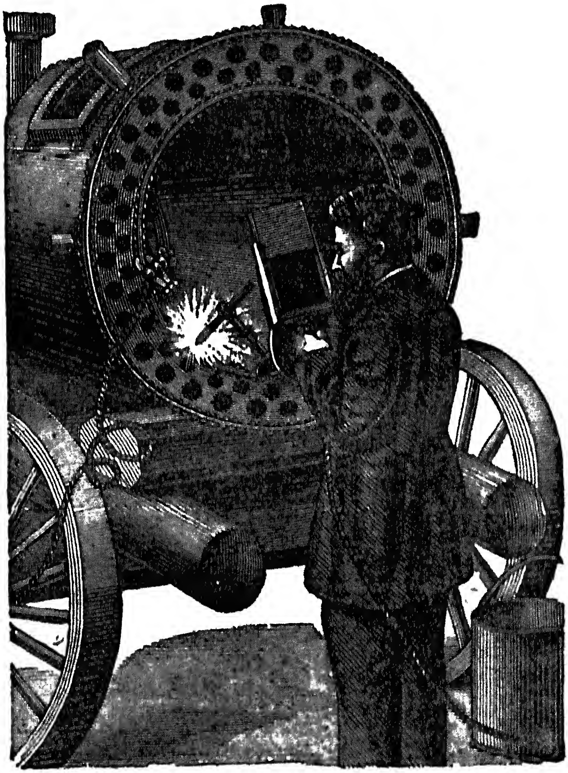


FIG. 88.

of pulleys and parts of machines, for which it was extensively used in the Thomson-Houston factory. Welds made by this process have been severely tested and in every case it has been found that the weld was quite as strong as the other portions.

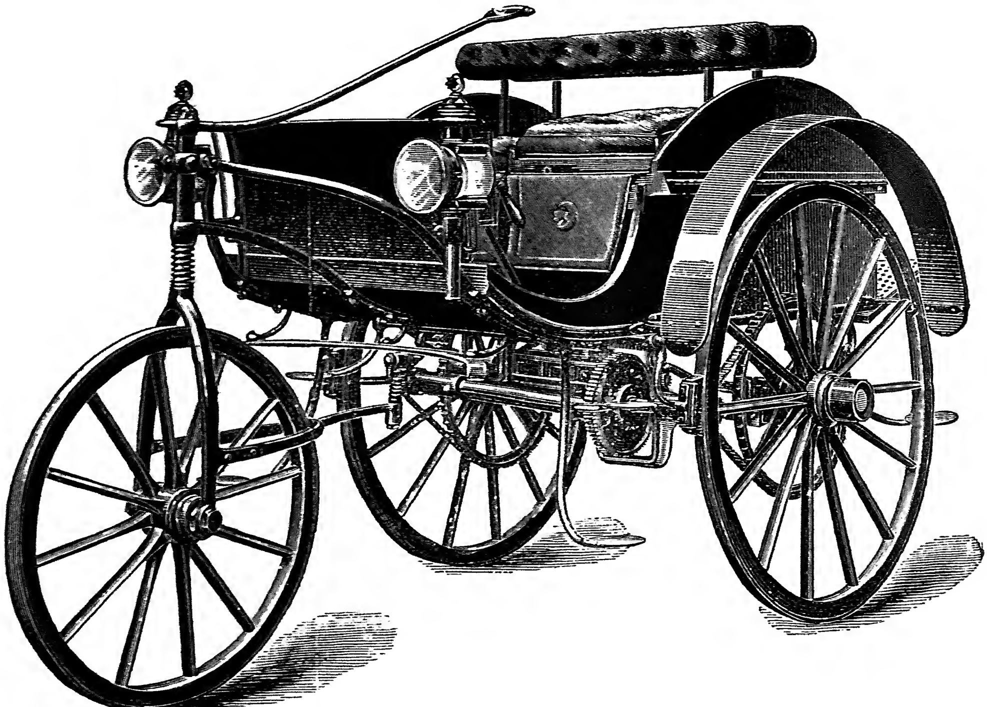


FIG. 83

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Bernardo's process consists in making the metal to be welded the negative pole, the positive pole being a carbon rod. This process has been employed to a considerable extent for repairing metal plates *in situ*, as, for example, the plates of a boiler. In order to weld together two pieces of boiler-plate, one of the terminals of a dynamo or set of accumulators is attached to the plate, and the other to a carbon rod an inch in thickness, held in a portable insulating holder; the metal is then touched with the rod, which is immediately withdrawn from a quarter to half an inch, thus forming an arc, as shown in Fig. 88, which is taken from a photograph.

The metal at the point where the arc is formed melts immediately like wax, and runs perfectly fluid. When looked at through the dark glass employed to shade the eye from the glare of the arc, the latter appears like a blow-pipe flame, and is manipulated in very much the same way.

The use of accumulators makes the whole apparatus easily portable, so that it can be carried to the place where the repair is required, instead of the plates having to be taken out and carried to a forge, and then brought back and replaced.

CHAPTER XVIII

ELECTRICITY IN WARFARE

ELECTRICAL TORPEDOES.—I mentioned in Chapter XI. that some of the earliest submarine electric cables were constructed for the purpose of exploding mines from a distance. Since that time submarine mines or torpedoes have been invented, and brought to a very high state of perfection.

Torpedoes, such as those of Whitehead or of Brennan, which can be propelled through the water, to attack a hostile vessel, are almost all worked by purely mechanical means without the aid of electricity, and therefore do not come within the scope of this volume.

In the case of fixed or stationary torpedoes or submarine mines, however, this is not the case, as these are almost invariably controlled and fired by means of electric currents. The earlier submarine mines were fired mechanically on being struck by a vessel passing over them, but the use of mines of this kind, even when they are of the most perfect construction, is attended with extremely serious disadvantages. In the first place, the operation of laying them down is an exceedingly dangerous one, especially if the sea is at all rough, for the firing arrangement has to be placed within the torpedo before it is moored, and as soon as this

is done it is liable to be exploded at any moment by an accidental jar. Another serious disadvantage is that, unless a secret channel is left open for the passage of friendly vessels, the torpedoes will prevent their entrance into the harbor just as much as hostile ones; and if such a channel is left it may be discovered and made use of by the enemy. Or again, a friendly vessel entering the harbor may, through bad weather or the mistake of a pilot, come in contact with one of the mines and be destroyed. Finally, when such a system of mines is laid down, the operation of taking them up when no longer required is one which is even more dangerous than that of laying them down.

All these defects are entirely obviated when the mines are fired by means of electric currents which can be controlled from the shore; and the only disadvantage attending the employment of the latter system is the possibility of the enemy obtaining access to the firing station, or to the cables connecting it with the mines, and rendering the torpedoes harmless by cutting the cables.

The disadvantage arising from this possibility is, however, a small one compared with those attending the employment of purely mechanical submarine mines, and therefore those now employed for the defence of harbors and river estuaries are almost invariably controlled and fired electrically.

Electrically controlled torpedoes may be divided into two classes—viz., those which are fired by closing the circuit on shore when a hostile vessel is observed to be sufficiently near to insure the explosion taking effect; and, secondly, electro-contact torpedoes, or those in which the circuit is closed by means of a circuit-closer, either contained in the torpedo itself, or in a small buoyant vessel moored to

the torpedo by a chain or cord of such length as to keep it a short distance below the level of the water.

The system of firing by observation is only practicable in clear weather and by day, or with the assistance of the electric light, while the electro-contact system can be employed at any time. On the other hand, the electro-contact torpedo will only explode when the circuit-closer is actually struck by the vessel, and as torpedoes have to be moored at a considerable distance apart, in order that the explosion of one may not explode its neighbor, the explosion of one of the torpedoes forming a line of defence would necessarily greatly reduce the chances of a ship coming into collision with an electro-contact mine, though it might easily pass near enough to be destroyed, or at any rate disabled, by a submarine mine fired by observation. Thus the most complete safeguard is afforded by a combination of the two systems.

Submarine mines of either class are usually charged either with some form of dynamite or with wet guncotton, and these can only be exploded by means of a bursting charge formed of some detonating composition, and the most suitable material for this purpose has been found to be mercurial fulminate. The fuse is usually fired by the heating, by means of an electric current, of a fine wire, usually of platinum, or an alloy of platinum with silver or iridium, imbedded in a mixture of finely-powdered guncotton and mealed gunpowder in equal parts. Below this is placed the bursting charge of mercurial fulminate. Fig. 89 shows a fuse of this kind, which is employed for submarine mines by the British Government. Fig. 90 shows a form of circuit-closer suitable for electro-contact torpedoes, designed by Colonel Bucknill, and described by him

in a recent volume of "Engineering," to the editor of which journal I am indebted for this and the preceding illustration. MM is a permanent horseshoe magnet, to which a ball, B, is attached by means of a spring, as shown in the diagram.

If the buoy containing the apparatus is struck by a vessel this ball is drawn sidewise against a silk cord connected

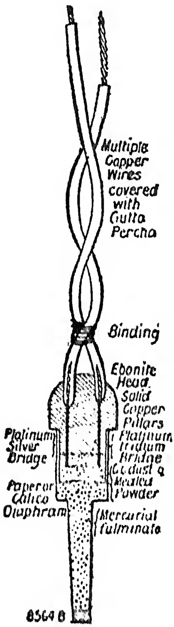

Fig. 89.

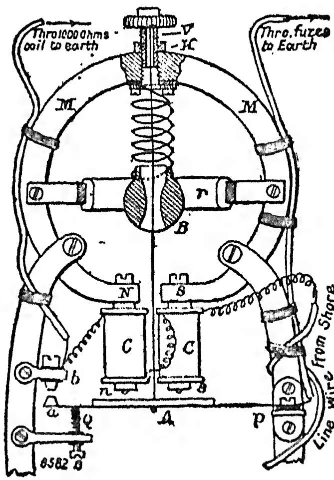

Fig. 90.

with an adjusting screw at one end, and with a spring detent at the other. This pulls down the detent and releases a wheel driven by clockwork, which then makes a complete revolution slowly, during which period the cable is connected through the fuses to earth, so that the mine can be fired if desired. The effect of its having been struck is automatically indicated to the operators on shore, and the

time taken by the rotation of the wheel gives them time to discover whether the circuit-closer has been operated by the shock of a countermine or by a blow from a hostile vessel.

To the poles, NS, of the magnets are secured the cores of two low resistance electro-magnets, CC, one end of the coil wire being connected with the line, and the other to a contact-stud, *b*. The armature, A, is secured by a spring to the fixed insulated point, P, whence an insulated wire is carried through the fuses to earth. The other end of the armature spring carries a contact-stud, *a*, which engages with *b* when the armature is attracted to *ns*, the poles of the electro-magnet, to which it is prevented from permanently adhering by means of two small ivory pegs fixed to the under side of the cores. The strength of the armature spring can be adjusted by means of a second spring, Q. An India-rubber ring, *r*, tied to a metal ring prevents the ball, B, from oscillating too violently. When this apparatus is employed as a detached circuit-closer for a large mine moored below it, the stud, *b*, is earth-connected through an interposed resistance of about 1,000 ohms, and in all cases P is connected to earth through the fuses. This circuit-closer can be used either for firing the mine by observation or by contact.

In firing by observation its action is as follows:

The coils, CC, are wound so that a negative current from the shore increases the normal polarity of the soft iron cores; consequently when the negative pole of a firing battery is connected with the line, a current passes through the coils, CC, and through the 1,000 ohms resistance to earth, causing the armature, A, to be attracted to the electro-magnet, and thereby sending a current from the fuses to the earth, the

resistance on the fuse circuit being low enough to cause the mine to be exploded.

If, on the other hand, it is desired to fire the mine by contact, the negative pole of a weak but constant battery is connected to the line, and when the circuit-closer is struck, the armature is held up mechanically, and retained in that position by the magnetic attraction. The signalling battery gives a signal to the shore, and the firing current can now be switched into the line or not as desired, the mine struck being indicated at the firing station by the deflection of a galvanometer, and by causing an electric bell to be rung. Only one mine, with a detached circuit-closer arranged in this manner, can be attached to the same line, but when the apparatus is employed for mines to be exploded by contact only the wire from *b* through the 1,000 ohms coil is omitted, and several mines can then be connected with a single cable, either one after the other, or in a bunch.

Gun-Firing by Electricity.—Electrical arrangements are now very frequently adopted for firing all the guns in a battery simultaneously, or for firing a broadside from a man-of-war.

In the latter case the conducting wires are carried to the *conning-tower*, the shot-proof tower from which the captains of our modern turret-ships will direct the evolutions of a vessel during a naval engagement.

When the vessel is approaching an enemy's ship the gunners will keep each gun trained upon the enemy's vessel, and the captain will depress the button at the moment that he considers the right one for delivering the broadside. This arrangement will probably prove to be of the utmost value, as there is little doubt that in the next naval engagement the first effective broadside will sink or totally disable

the vessel receiving it, so that the result of a combat between two ironclads will mainly depend upon which vessel is able to fire first with effect.

The Telegraph and the Telephone in War.—The establishment and maintenance of an effective system of telegraphic communication between the different armies, and the different portions of each army, engaged in a campaign, has already been proved, by the experience of several great wars, to be of the utmost possible importance; and in addition to the fixed lines, carried upon poles or underground, portable lines are employed to a considerable extent, the line-wire being wound upon drums, which are carried on to the field of action, so that the commander-in-chief can telegraphically direct the operations even of the divisions actually engaged in fighting.

It might at first sight appear that the telephone could be employed with advantage to replace the ordinary telegraphic signalling instruments for such a purpose as this, but, as is pointed out by Messrs. Preece and Maier in their work on the telephone, its use under such circumstances is open to very serious objections.

In the first place, it is an invariable and salutary rule in the British army that all important orders must be delivered in writing, and the value of this rule is shown by the number of instances on record in which fatal blunders have been directly traced to the misapprehension of verbal orders. Now, as is pointed out in the work alluded to, an order transmitted by telephone is worse than a verbal order delivered from one person to another, as it will probably be transmitted verbally between two clerks who do not understand its meaning, by means of a mechanism which, although of the greatest value and ingenuity, is far less

efficient than the human voice addressed directly to the ear: and in illustration of this an incident is mentioned which occurred on a military line, fortunately, however, in time of peace, when some intelligence as to the whereabout of a submarine mine case at the Needles was received as an urgent demand for a case of needles.

If such mistakes as this can occur in time of peace, there can be no doubt that they would be much more frequent if the telephone were employed upon the battlefield, where the roar of cannon and the rattle of musketry would be reproduced by the transmitters and greatly interfere with the distinctness of reproduction of a message.

There can be no doubt, however, that there will be great scope for the use of the telephone in camps, not in the immediate presence of the enemy, for carrying out the routine business of the camp, promulgating orders, requisitions, etc., and its use would not only reduce the number of orderlies at present required to conduct the large amount of correspondence of this kind in a large camp, but would very greatly diminish the loss of time between the asking of a simple question and the receipt of the answer. The telephone is also found to be of considerable use as a telegraph receiver for employment in field telegraphy, as it is exceedingly sensitive, so that communication can be carried on through faulty lines, or even through bare wires simply laid upon the ground. This sensitiveness also enables much smaller battery power to be employed than is required when ordinary telegraph receivers are used. Another very great advantage is that when the telephone is used as a telegraph receiver it never requires adjustment, and this often saves a considerable amount of time in rapidly running out a line and establishing communication.

Messrs. Preece and Maier inform us, moreover, that the buzzing signals given in the telephone receiver are much more easily picked up by signallers trained to read flag and lamp signals than those of the Morse instruments. The current used is an intermittent one, and this intermittent current produces a musical note in the receiving telephone.

This system has been used with great advantage in our recent wars, including the Egyptian and the Bechuanaland expeditions.

All the messages from the field of Tel-el-Kebir were sent in this manner, and in the Nile expedition it was found on several occasions that its use enabled very important messages to be sent through portions of a long line, which, owing to faults, were unworkable by ordinary instruments.

The telephone is used to a considerable extent, and with the greatest advantage, in rifle practice, both in this country and in Germany, for communicating between the markers at the target and the firing station.

CHAPTER XIX

MEDICAL ELECTRICITY

THE electrical phenomena presented by the tissues of the living animal body, obscure as the subject is, deserve a brief mention; especially as electricity is now so largely used in the treatment of various diseased conditions.

Muscle and nerve are the living tissues *par excellence*, and it is their changes of electrical state which have been most studied.

Currents of Rest.—If one end of a cylindrical muscle is

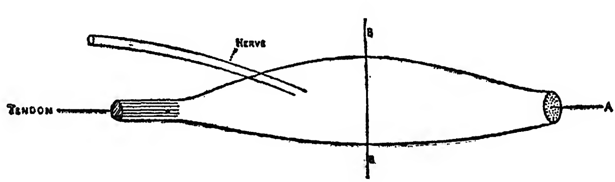

FIG. 91.

cut off, as shown in the diagram, Fig. 91, and one electrode of a galvanometer of appropriate construction placed on the centre of the cut surface at A, while the other electrode is placed on the equator of the muscle, BB, the existence of an electric current between the two points will at once be clearly evident. The existence of a similar current in

piece of a nerve-trunk similarly treated can be demonstrated in the same manner, though the nerve current is much feebler than the muscle one. These currents are termed "Currents of Rest"; but whether they are natural or artificial—*i.e.*, whether existent in perfectly healthy tissues, or only as a result of injury—is a question which is still *sub judice*. Those who maintain the latter view lay stress on the undoubted fact that the surface of the quiescent frog's heart, which is practically a mass of muscle, is *iso-electric*—*i.e.*, on whatever two points on its surface the electrodes are placed no current flows through the galvanometer.

Currents of Action.—Whatever be the truth as regards the currents of rest, there is no question as to the occurrence of marked changes of electrical condition when a muscle or a nerve is stimulated. If, in a muscle prepared as above, the galvanometer is showing a distinct current of rest, as soon as the muscle is made to contract by stimulating its nerve, the needle of the galvanometer swings back toward zero, a phenomenon known as the *negative variation* of the current of rest. But a like electrical change can be demonstrated even in the absence of any current of rest—*e.g.*, at each contraction of a frog's heart a very distinct current shows itself. Hence the term "Current of Action" is preferred by those who deny the existence of any natural "Current of Rest." This change of electrical state in the muscle precedes the change of form which is the visible result of stimulation, and, like the contraction, travels in the form of a wave, each portion of muscular substance, as it contracts, becoming negative to those portions which have not yet contracted, or which have returned to a state of rest.

A similar wave of change of electrical state traverses a

nerve which has been stimulated; it travels at the same rate as the nervous impulse, *i.e.*, about twenty-eight metres per second in a frog's nerve—a rate so much slower than that of an ordinary electric current, that by itself it suffices to show that the nervous impulse is something essentially different from an electric current. The association of such electrical changes with vital phenomena, when first observed, led some too hasty people to the conclusion that they were identical, a view to which are due the foolish statements, *e.g.*, "Electricity is Life," which figure so prominently in the advertisements of various quacks.

The use of electricity for medical purposes depends largely on the fact that the activity of the muscles, nerves, and other tissues, normally dependent on that of the central nervous system—*i.e.*, the brain and the spinal cord—can, nevertheless, be evoked by other means, mechanical, chemical, thermal, or electrical. The following facts illustrate the nature of the influence exerted by electricity upon the nerves and muscles.

When a continuous current is passed into a nerve attached to a muscle, a single contraction of the muscle takes place, and a similar contraction occurs when the current is cut off; but so long as the current is traversing the nerve the muscle remains quiescent. Although, however, there is no visible change in the nerve-muscle preparation, the condition of the piece of nerve traversed by the current is profoundly modified; it is in a condition known as *electrotonus*, and it can readily be demonstrated that in the vicinity of one electrode its excitability is markedly increased, while in the vicinity of the other it is correspondingly decreased. The passage of an intermittent current, consisting as it does of a rapid succession of shocks, into the nerve of a nerve-

muscle preparation, throws the muscle into a state of contraction which persists as long as the current is passing, or until the muscle is exhausted. The muscle may also be made to contract by the direct application of an electric current, continuous or intermittent, to its substance, without the intervention of the nerve; muscle substance is, however, much more sluggish in its response to an electrical stimulus than is nerve substance, and unless the stimulus acts during an appreciable period the muscle fails to respond. Hence if the minute nerve filaments which ramify through a muscle be destroyed by disease or paralyzed by drugs, the muscle cannot be made to contract by the intermittent current, whereas the continuous current affects it readily.

Electricity is employed by physicians both for diagnostic and for therapeutic purposes. As a diagnostic agent its chief use is in cases of paralysis, to aid in deciding the important question as to the site of the morbid process, or fault, to use a telegraphic term, which has deprived the brain of its power over a muscle or group of muscles. The lesion may be in the central nervous system itself, or anywhere along the tract of communication between this and the muscle or muscles affected—*i.e.*, it may be central or peripheral. In the latter case the minute nerve filaments, which ramify through the muscle substance, waste away, so that the muscle can no longer be made to contract through their agency; in such a case the muscle makes no response when stimulated by the intermittent current, whereas its reaction to the continuous current is even more prompt than usual. There are other distinctions, qualitative and quantitative, on which it is unnecessary here to dilate.

The therapeutic uses of electricity are manifold. One of the most important results from its power of stimulating

muscles into action. When the communication between a muscle and the central nervous system is impaired by disease, the muscle, being unused, rapidly wastes away, and in cases which tend to recover there may be little muscle tissue left by the time that the natural process of repair has restored the integrity of the affected communication, so that the paralysis is permanent. In such cases the physician is able, by the aid of electricity, to give the paralyzed muscles such regular exercise as suffices to keep them healthy until the central nervous system has had time to regain its power over them.

Electricity is often of great use also in cases of neuralgia, rheumatism, painful spasm, etc. Thus, a nerve-trunk may be in an unduly excitable condition, or may be conveying to the brain impulses originating in a disordered peripheral organ; by putting such a nerve into the electrotonic condition, its excitability or conductivity may be modified in such a manner as to stop the passage of such morbid impulses, so relieving pain. It is easy to see, however, that in such cases the character and direction of the current to be employed are points requiring careful consideration; and if used without knowledge the remedial agent may aggravate instead of alleviating the morbid condition.

Electricity is also frequently employed for its chemical and thermal effects. Electrolysis may be set up in a tumor, so initiating processes which stop its growth, or cause its gradual destruction; or in an aneurism, to cause coagulation of the blood and consequent consolidation of the aneurism. For cauterizing purposes, also, in parts of the body difficult of access, the electric current is frequently employed to heat a wire previously placed *in situ*.

As an illuminating agent electricity is frequently em-

ployed to examine various passages and hollow organs of the body, the pharynx, stomach, bladder, urethra, etc.

In conclusion, it may be well to remark that electricity is not a universal panacea, and that it does not act like a magical incantation. When the effect to be obtained is clearly realized, and the means employed are adequate and appropriate, the use of electricity will often be of the greatest benefit; in the absence of these conditions it is far more likely to be harmful. It is only fair to observe that the majority of the people who vaunt their marvellous belts and other electrical appliances appear to have borne this fact in mind, and avoid harming their patrons by supplying apparatus which is as innocuous as it is useless.

CHAPTER XX

MISCELLANEOUS APPLICATIONS OF ELECTRICITY

IT WOULD be impossible in the space at my command to enumerate all the various useful purposes to which electricity is now applied, but I have thought it well to devote a short chapter to a few interesting applications of electricity which could not suitably be included in any of the preceding ones.

A very interesting and useful application of electricity in private houses is one which is now extensively adopted in America for enabling private dwelling-houses to be shut up during the absence of their owners without danger of being broken into by thieves, thus doing away with the necessity of employing caretakers.

The system is a very simple one, and consists in carrying a continuous wire in front of every door and window in the house, in such a manner that none of them can be opened without breaking or cutting the wire. One end of the wire is put to earth, while the other is carried to the central station established by the company working the system, and connected to one of the terminals of a galvanometer, the other terminal of which is put to earth. An electric current is kept continuously flowing through each of the circuits thus meeting at the central station, either by inserting batteries in the circuit, or by means of a dynamo at the

central station. The galvanometers are watched day and night, and if any one of the circuits is broken the fact is at once indicated to the watchman by the needle of the galvanometer going to zero. When this happens the police are immediately communicated with, and a man is at the same time sent round from the central station to repair the breakage and to find out whether the interruption was due to accident or not.

FIG. 92.

Soon after the introduction of this system into the city of Washington a negro attempted to effect an entrance into a house protected in this manner. He was aware that the house was protected in some mysterious way by means of a wire carrying an electric current, and thinking to make quite sure of obviating any disagreeable effects to himself, he took the precaution of cutting the wire, and then watched for a considerable time to see what would happen. As he was unable to perceive any effect as the result of his action, he then effected an entry into the house. The police, however, had been communicated with, and had been watching the burglar the whole time, so that he was immediately followed, handcuffed, and removed to the police cells, much to his disgust and astonishment.

Electric bells are now in very general use in this country, as well as in America, and they seem almost too well known to need description, but perhaps a brief account

of their construction and manner of working may not be without interest.

The ordinary form of electric bell, with its cover removed, is shown in Fig. 92. It consists of a electro-magnet in circuit with a battery, the circuit remaining open when the bell is not in use, and being closed by some form of push-button. When the circuit is closed, the armature of the electro-magnet is attracted by the iron core within the coils, and the hammer attached to it strikes the bell. When the armature is thus drawn toward the electro-magnet, the circuit is broken, the electro-magnet becomes demagnetized, and the armature springs back to its original position, and again completes the circuit through the contact point shown in the diagram. As long as the push-button is kept pressed down the bell will continue ringing.

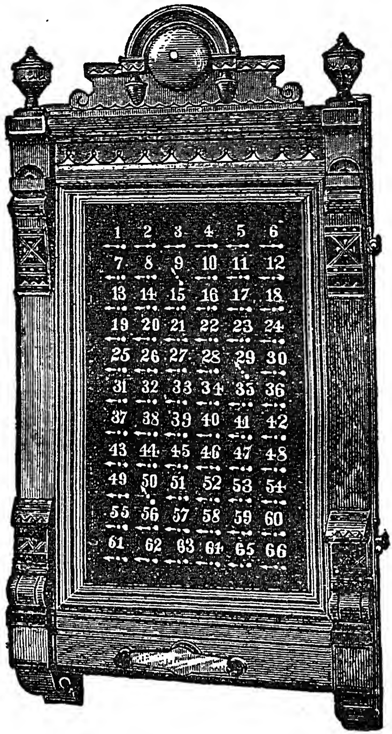

FIG. 93.

This is the system generally employed in private houses, but in hotels an indicator is usually attached to each bell, and when the push-button is depressed, not only does the bell ring, but the indicator falls, and, as long as it is down,

completes the circuit without the intervention of the button, so that the bell continues ringing until the servant whose business it is to answer it has replaced the indicator, thus insuring that the call should not pass unnoticed. The indicators belonging to all the rooms in a hotel are usually arranged upon a single board in the manner shown in Fig. 93.

Many shops and warehouses are now provided with electric alarms, which set a bell ringing if the temperature rises to such an extent as to indicate that a fire has broken out, or, if no one is living on the premises, a signal is automatically sent to the nearest fire station. Similar alarms are now employed in greenhouses to ring a bell in the gardener's cottage when the temperature rises above or falls below certain limits.

All the clocks in a large establishment can be regulated, if desired, by means of electric currents, from one central one, so that it is sufficient to have one first-rate clock in the system, the others, of inexpensive construction, being made to keep exact time by the central regulator.

Another application of electricity of quite recent discovery, but which promises to be of considerable importance, consists in its employment for decomposing the offensive gases in our sewers, and removing the poisonous properties of their fluid contents, so that after such treatment they may be allowed to discharge into rivers without fear of spreading diseases.

The employment of electric currents for exploding submarine mines would naturally suggest the advantage of using electricity in the same manner for exploding blasting charges in mining operations, and, as a matter of fact, it is now employed to a considerable extent for this purpose.

A very striking example of its advantages was given in the blowing up of the rocks at Hell Gate in New York Harbor some years ago, when a mass of many thousand tons of rock was blown up by means of dynamite cartridges inserted in channels which had previously been bored by divers in all directions through the rock, and which were exploded simultaneously by the passage of an electric current.

One more application of electricity I must mention, but only to deprecate it, and that is the proposal to employ it for the execution of criminals, which has been recently made in the United States.

Every one who has any competent knowledge of the subject knows that the greatest possible uncertainty attaches to the effects of electric discharges upon human and other animal life, and though there would be no difficulty in employing a current of sufficient strength to insure immediate death, this result could only be attained with absolute certainty by the use of currents which would terribly disfigure the body of the criminal, and the legislature of the State of New York has expressly stipulated that the currents must not be such as would cause disfigurement.

I have no hesitation, therefore, in maintaining that it would be a most retrograde step to replace the present simple and humane method of terminating a criminal's existence by one which in some cases might allow him to escape with impunity, and in others might subject him to horrible tortures before life became extinct.

ELECTRICITY IN MODERN LIFE

SUPPLEMENTARY

By FRANKLAND JANNUS

INTRODUCTION

During the past five or six years the advances in the various branches of electrical science have been many and decided; and although perhaps not exploited in the sensational manner of the early steps in the art, they have been of revolutionary character in many instances, and, to say the least, of the very greatest importance. The impossible of a few years ago is the imminent of to-day and the ordinary practice of to-morrow.

The electrical art is progressing by gigantic strides, each one of which brings it more intimately into the daily routine of modern life; and especially is this true of the United States, where capital is ever ready to encourage promising enterprises, and where new systems constantly find fresh and comparatively unoccupied fields for development, where the same end has been sought and only partially accomplished by inferior and inadequate methods.

In the following pages it is the intention to point out the advances in practical application which have occurred during recent years.

Professor de Tunzelmann has dealt very carefully with the complex theoretical propositions involved in the study of this art. He has had no easy task to reduce them to the simple forms in which they appear, and in which they should appeal to the non-professional reader. These questions will therefore not be touched upon by the present writer, and the following pages will contain, in as non-technical language as possible, a brief mention and account of those prominent features of development in the electrical art which are believed to be of general interest as entering into the application of electricity to modern life.

F. J.

New York City, August, 1900

HEATING BY ELECTRICITY

WE have seen that the passage of an electric current through a conductor is accompanied by the generation of heat in the conductor. When the conductor is of ample size for the current it is to carry, the heat produced therein may be almost imperceptible. Many circuits are in use, including miles of wire and thousands of lamps, fan motors, and other apparatus; and in these cases the cost of the conductors is so great that most careful calculations are made so as to use wires, in different parts of the circuit, of just sufficient size to supply the heaviest demand for current upon them from the apparatus with which they are connected, without becoming heated to a degree which could set fire to adjacent woodwork or damage their own insulation. From this it will be understood that the constant effort and care of the modern electrician is to prevent the overheating of his conductors by the passage of the electric current in any and all installations for lighting or transmission of power.

The process of welding metals together by electricity referred to on page 263, on the other hand, requires that the pieces to be united, which of course must be conductors, shall be heated almost to the melting point at the place of contact, when the two thus softened ends are pushed together and effectually and permanently joined.

This machine consists of a table upon which are two clamps, an inch or so apart and operated by hand levers, to secure and hold the ends of the pieces to be joined,

which may be the extremities of a band of iron to be made into a hoop. The ends of the band, previously bent to a circle, are grasped by the clamps and held together endwise. The current is now turned on, and in a few seconds the touching ends of the hoop become red hot, and very soon a dazzling white. At this point the clamps are pushed together by a screw at the end of the table. This brings the softened and semi-molten metals completely together. The flow of current is now stopped, and in a few seconds the weld will cool sufficiently to allow the hoop to be removed.

Under the table is placed a large induction coil, the primary coil of which is supplied with alternating current from a suitable generator. The secondary coil is made of very large wire, of only a few turns, the ends of which are connected to the clamps, and its current passed through the clamps on the ends of the metal to be joined, which are held between them. When no work is in the machine, the ends of the secondary coil are separated, and if the primary current is still flowing, no current will be generated in the secondary coil; but just as soon as two pieces of metal are fixed in the clamps, and their ends brought together, current will be generated in the secondary coil in very large volume, and such current, flowing through the ends of the piece, will heat them with the results described. This method has a wide range of usefulness, and has already been extended to the practical welding of the abutting ends of heavy railway rails, while in place in the track, the welding apparatus being carried by a car moving thereon. In addition to welding practically all sizes of pieces, different metals are so united, a thing entirely new, and including joints of copper to iron,

steel to brass, copper to silver, brass to German silver, and many other combinations useful in the arts, but previously not practically attainable.

Another very interesting application of the heating capacity of an electric current has been practically applied in the construction of the electric liquid forge. This is an apparatus for the heating of pieces of metal by electric current to the same extent and for the same purpose as in the well-known blacksmith's forge. This is accomplished by means of apparatus, such as shown in Fig. 94, in which *A* is a tank mounted on any sort of insulating support, as for example, wooden legs. The tank *A* is kept nearly full of a liquid *B*, which is rendered a fairly good conductor of electricity by the admixture therewith of a suitable quantity of salt. *C* is a connection to the liquid *B* from the positive conductor of a continuous current supply circuit. Metallic contact rails *D* connected to the other, the negative side of the supply circuit, are placed around the edges of, and sometimes across the top of, the tank *A*, and are well insulated therefrom. A pump *F* is also provided for pumping some of the liquid into an upper tank *a*, from which it is allowed to run down again into the main tank, and thereby maintain a circulation in said liquid. When a piece of metal, as *d*, is laid upon the rail *D* with its end immersed in the liquid *B*, the current will pass from the liquid to the piece *d* and through said piece to the rail *D*, and back to the generator. In passing from the liquid to the piece to be heated, the current forms an arc enveloping the immersed metal and rapidly heating it to any desired degree. When hot enough, the metal is withdrawn by means of an ordinary pair of tongs and worked upon the anvil or under the

drop forge as desired. It will, of course, be understood that the rail *D* may be provided with auxiliaries, and with movable arms that may be adjusted into any posi-

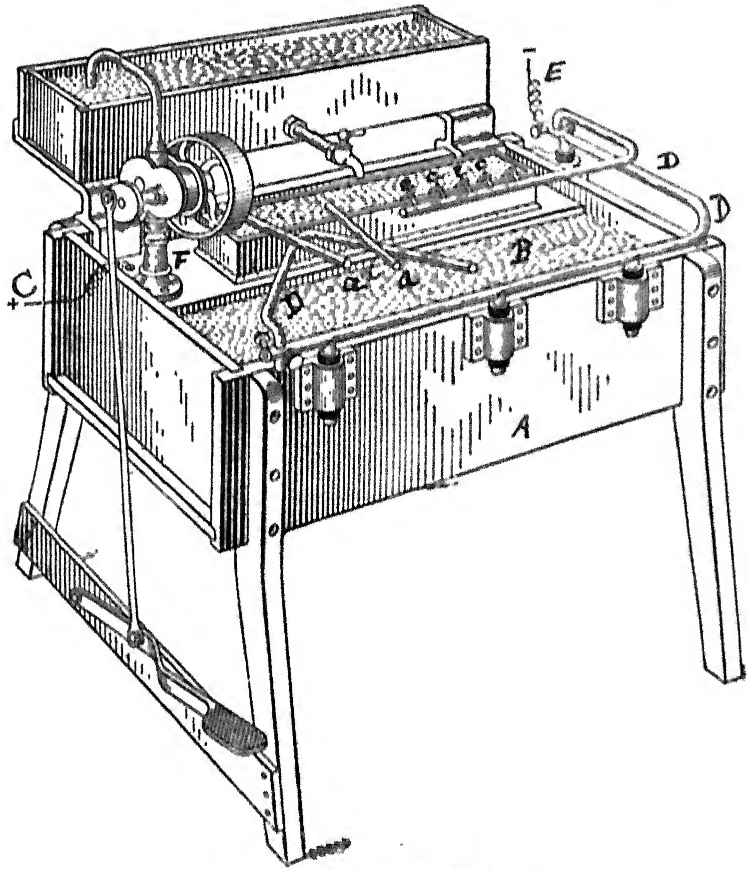

FIG. 94.—Electric Liquid Forge.

tion about the tank, which would be needed to facilitate the work, also that the metal to be heated should be first placed in contact with the rail and then with the liquid.

We have seen that an electric current has two charac-

teristics; first, that of force, called tension or voltage, which indicates the speed, so to speak, at which it travels; its other quality, which does most of the heating, is that of quantity or volume. It was found in electric welding that currents of enormous quantity but of very little force were required, so that in a welding apparatus a person, without the slightest danger, could touch the conductors carrying the current which produces the enormous heat necessary; for the reason that the tension is low and the conductors necessary to carry a current of such quantity afford a better path to the current than the human body, which will therefore not leave its conductors. But even if it did, no injury would result so far as animal life is concerned. It is the shock from the force of the invisible blow dealt by a high tension current passing through the body that kills, and the same current which would kill a dozen men joined hand to hand, could, if transformed into a current of less force, or lower potential, and larger quantity, be passed through them without injury.

Acting upon this, electric heaters have been constructed which consist of a number of insufficient or bad electric conductors through which a current passes, and in so passing heats them. These conductors are arranged in groups attached to a suitable insulated base which may be placed in a street car or in a room, and will radiate heat in precisely the same manner as the well-known steam radiator. Their great advantage, however, is that they may be placed wherever the heating effect is desired, can be turned on or off at will from any convenient point, emit no odor, and can be operated from the ordinary supply of current for lighting. At present, however, these heaters are princi-

pally applied to electrically operated street cars, for the reason that the kind of current by which heating devices would be most economically operated is not usually available, and the currents that are available, being produced for a different purpose, cause the expense of heating by electricity to exceed that of the ordinary methods—steam, hot water, hot air, or stoves—that are more familiar, and with which buildings are already supplied.

We all know that cooking can be effected on a gas range much more conveniently than by the use of coal, but that the gas range is much more expensive to operate. That is the condition of the electric heater at the present day. It is also well known that a fuel gas can be made and distributed at a far less cost than illuminating gas, and can then be used for cooking purposes economically, being much cheaper and giving more heat than illuminating gas in similar quantity. The proper current for heating by electricity stands in the same relation to lighting or power as does the fuel gas to the illuminating gas. Notwithstanding the ready availability of gas, however, there are instances in which heating by electricity is applied most successfully and conveniently also to cooking. This is done by providing each vessel with a heater composed of a coil of wire or suitable thin strips of metal arranged so as to form a part of itself, and when heated by the passage of a suitable current will radiate heat into the vessel without coming into contact with its contents. Instead of placing a kettle upon the stove to boil, you simply connect it with the conductors, and the current will do the rest. The heat developed by the electric current, as applied to cooking utensils, is the steadiest and most gradual known. There is no flashing or

sparking, nor is it concentrated at a single point, therefore the food is not liable to be burned as by the intense heat of the gas stove, and with proper current—namely, that of small force and large quantity—there is absolutely no danger whatever.

While electrically operated cooking utensils are not yet in general use, they are made by at least three firms in this country, and the apparatus comprises everything needed to carry on the operations of cooking. The construction of these vessels may be divided into three classes. One, that in which the heating coil or wire is

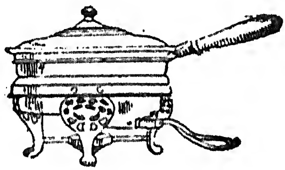

FIG. 95.

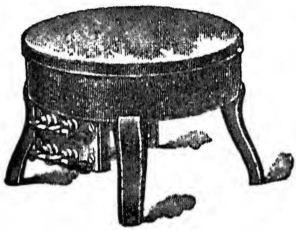

FIG. 96.

incorporated into the vessel itself, as in the teakettle. In this apparatus the heating coil, which is a bad conductor, is placed in the bottom of the vessel and is surrounded by an insulating material, which prevents the current escaping from the heating wire or strip to the metal of the vessel, which is in itself a good conductor of heat. A heating conductor covered with enamel similar to that with which cooking utensils are often coated, under the term porcelain-lined, gives good satisfaction, and is safe, clean and durable. Fig. 95 is a chafing dish on this principle. Class two includes a small stove upon which the vessel to be heated is set. In the case of electrical apparatus these are made small and may be set upon a table,

or such an arrangement as that shown in Fig. 96, with an ordinary saucepan upon the stove, the stove itself, when the pan is removed, being available for heating cakes, bread and the like. An oven is constructed which is heated by a device similar to the stove, the heater being built into its lower portion and radiating directly into the oven. One other form of arrangement is in use, and this comprises a coil which is in itself so constructed that it may be immersed directly in the liquid to be heated, so that a large tubful might be heated wherever it happens to be. Another very convenient use for this immersion coil is for the well-known farina kettle,

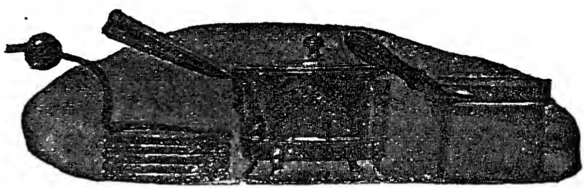

FIG. 97.—Farina Boiler.

Fig. 97, the coil being immersed in the water between the kettle and the pan which would ordinarily be set upon the stove. The well-known enamel ware is exceedingly convenient for use in this connection, since the enamel is an exceedingly good insulator, and will prevent the escape and waste of current in case there should be a leak from the immersed coil. With the farina kettle the coil heats the water contained in the pan, and the vessel containing the farina or other delicate material to be cooked, standing in the heated water, becomes heated therefrom in the usual way. Heaters are made in various sizes and shapes. In nearly every residence there is a cold corner which it is difficult to warm, or it is often desirable

to heat certain rooms, such as the nursery or sick chamber, to a higher temperature than the rest of the house. In the spring or fall, when the furnace is not running, the bathroom is chilly, or possibly, in extremely cold weather, the temperature needs to be raised ten degrees or more to make it comfortable, and how to get this extra heat is a problem that has been difficult to solve.

It is not claimed that it is economical to heat residences throughout by electricity, unless the current is produced at a very low cost; but for such purposes as have been mentioned, or for heating small offices, no other system can compare with the electric air heater in efficiency, cleanliness and convenience. It commences to throw out heat the moment the current is turned on, and there being no combustion, there is consequently no odor.

The cost for current for operating electric heating apparatus cannot be easily given, because there are many variables which would prevent any definite statement being correct. First, the cost for current varies with the locality; in a city with very cheap fuel and liberal patronage, current can be supplied at a lower price than where fuel is high and the patronage limited. Second, the amount of current used will vary the cost, as it is the general practice to give discounts for the amount used over a stated quantity. Third, the operators can, in many cases, use much or little to perform the same amount of work. This last statement applies particularly to domestic apparatus—*i.e.*, forty minutes' current supply will cook a roast that requires to be for an hour and a half in the oven, yet a careless cook might leave the current on for the full time with no advantageous results. Water can be boiled in a teakettle with full current in

say fifteen minutes, and then kept boiling with one-fourth the full amount. In using a radiator it may be allowed to run at full load—that is, the full power of current pass continuously through it—without serious discomfort, yet one-third the full supply would be ample. To enable approximate estimates to be made by those not familiar with electrical terms, we can state that the usual incandescent lamp requires a constant supply of 50 watts of electrical energy. Take, for example, the teakettle; this requires 200 watts maximum, which equals four lamps. This amount of current is required for fifteen minutes to boil one pint of water (starting with everything cold), and then, by the operation of the switch, the current supply can be diminished and it can be kept boiling indefinitely, with only 50 watts, the current required for one lamp. Knowing the cost to operate a lamp for one hour, it is easy to compute the cost per hour for operating the different devices, if run continuously by the hour at a stated load.

There are many items now manufactured for use in the home, which, on account of the fact that they are only occasionally needed, use so little current that the cost for operating them is not appreciable, and would hardly be considered in comparison with the amount of comfort and convenience to be derived. For instance, the curling-iron heater, the chafing dish, seaming iron, small nursery stew-pan; all of these being articles which would not be sought or desirable in the kitchen, but exceedingly so in remote parts of the house—more especially when they could be had and used without dirt or disturbance, and could, in fact, be connected to a lamp socket and removed again in a few minutes. Another device is a heating pan,

which replaces the old-fashioned water bag, giving any desired degree of heat without danger of leakage, and also without the discomfort of being obliged to have the bag too hot at first, in order that it should last long enough to be worth while.

For summer cooking and laundry use, special rates can always be obtained, and the cost for electric heat, if care is used, will be found about as cheap as other fuels. Actual experience shows practically no change in the room temperature in summer where electric cooking is in progress.

TIME REQUIRED

Stoves and griddles are ready for use—*i.e.*, have reached a temperature for cooking—in from 5 to 8 minutes from time current is turned on. Broiler, 12 to 14 minutes; oven, 20 minutes; farina boilers, 6 to 8 minutes; chafing dishes, 10 minutes; stew-pan, 5 minutes; laundry irons, 8 to 10 minutes very hot; tailor's irons, 6 to 12 minutes; foot warmers, heating pads, 5 to 15 minutes; curling-iron heater, 6 to 8 minutes; plate warmer, 10 minutes; soldering iron, 5 to 8 minutes; glue pots, 15 to 30 minutes.

To boil water, starting with water and heater cold: stew-pan, 1 pint, 16 minutes; small teakettle, 1 pint, 15 minutes; 6-inch stoves (using suitable flat bottom vessel), 1 quart, 18 minutes; teakettle, 1 quart, 15 minutes; 2 quarts, 28 minutes; hot-water urns, 1 gallon, half full, in 35 minutes, full, in 1 hour; 2 gallons, half full, in 50 minutes, full, in 1 hour and 20 minutes; 3 gallons, half full, in 37 minutes, full, in 60 minutes; 5 gallons, half full, in 30 minutes, full, in 55 minutes. Very hot water,

about 175 degrees F., can be had in about two-thirds the time stated for boiling.

Water heaters can be constructed which will boil the quantities mentioned in about half the time, but the current required would be nearly double that mentioned for any standard articles. Coil heaters when immersed in a covered vessel give the following results, using maximum current; and after water boils will maintain it at the boiling point with one-fourth of the maximum: one pint in ten minutes, and so on, in accordance with the size of the coil and amount of current used. In one instance, however, electricity is now considerably used, namely that of heating tailor's irons, Fig. 98. The iron is provided with an insulated conductor imbedded near its lower face, through which the current continually passes, the great advantage being that the iron can be kept at practically a constant temperature, and its polished surface is not injured by contact with fire or by being placed upon a rough stove.

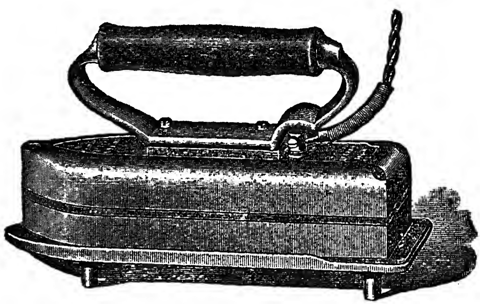

FIG. 98.—Tailor's Iron.

The steam laundry using gas for heating the ironing machine is a thing of the present. The electric laundry, in which all machinery is driven by electric motors and

the ironing machines heated by the same agency, will undoubtedly replace the former in the near future. In this connection the radical differences between the two systems of producing electric current, the continuous and the alternating, can perhaps be simply explained. Continuous current, that is current flowing always in the same direction, passes through the circuit, operating lamps or motors of the continuous current type, always with the same force, losing only what is consumed or what is lost by travelling over the conductors.

With the alternating current, however, the conditions are greatly altered. This current is generated in substantially the same kind of dynamo-electric generator as the continuous current, but it flows directly into the wires for distribution without being corrected or straightened by means of a commutator on the generator, and therefore has a back-and-forth movement; or you may say that the current is made up of an enormously rapid succession of small currents first in one direction or of one polarity, and then of the other. This alternating current serves to operate incandescent lamps just as well as that of continuous direction, and if there are any variations in the light given thereby, they are so small and so rapid as to be imperceptible to the eye. This current is also used to operate arc lamps with slight modifications in the automatic carbon feeding devices, but such lamps can also be used in continuous current circuits. The alternating current, however, possesses the very great advantage of being capable of transformation from a current of great force and small quantity, which traverses long lines of comparatively small conductors with little loss, into currents of small force and large quantity at the point of consumption. In the case

of a building provided with electric lamps, where it is desired to also use cooking or heating apparatus, the main high tension lines are tapped, and a small insulated box called a converter and containing only two coils of wire is provided. One of the coils is connected to the line, and the other is connected to the wires entering the building from which the lamps are supplied. There is no mechanical connection between these coils, nor are there any moving parts whatever in a converter. The current passing through the primary or supply coil acts inductively upon the distributing coil, generating a similar alternating current therein of a force and quantity corresponding to the size of the wire composing the secondary coil, so that the high tension current in the main lines can be reduced or transformed to an entirely harmless low-tension current entering the building. This reduction can be carried on indefinitely. A second transformer may be placed within the building, which, having its primary coil supplied by the current operating the lamps, will give out a current of still lower force and increased quantity suitable for the relatively economical operating of heating devices.

The general adoption of this plan is solely a question of expense. Current, particularly by alternating methods, is produced much more cheaply now than ten years ago, due to the immense improvements in the construction of generators. Slow-running dynamos of enormous size are now being used and connected directly to their driving engines, instead of a large number of small generators driven at high speed through belts and countershafts operated from one engine as formerly; it being well known that the proportion of the power developed by

the engine which is required to drive the belts and countershafting is very considerable.

DANGER TO LIFE

We frequently hear of electrical workers being killed by the current and from this naturally proceeds the belief that all electric currents are dangerous, even deadly, and that any contact with a highly charged electrical conductor will result in fatal shock. There is, however, much misunderstanding on this point. It is admittedly dangerous to play with fire, also to enter a crowded machine shop in full operation and to walk about carelessly without regard to moving parts or waving garments, and an electric power generating station would probably be a very dangerous playroom. Yet the electricians in charge survive their daily attendance upon and care of the most dangerous machines in regular operation. How do they do it?

We have seen that it is the characteristic of force, voltage, in an electric current which makes it dangerous to life. Also that in currents to be economically distributed over long distances, the characteristic of force must predominate; but it is also true that for an electric current to produce death, or the appearance of death, it must pass through the body. It is not sufficient that it gets into the system; it must also have an exit. For this reason there is always a dry wooden platform or floor about a high tension generator, so that if the attendant were to touch but one of the conductors forming a part of the circuit with one hand while standing upon the dry floor, which is a

good insulator, the current could not go through him and no harm would result; but let him do so and at the same time lean against a metal pillar or pipe connected with the ground, the current would go directly through him, and, if sufficiently powerful and continued for a few seconds, would produce death. A high tension electric current strikes a terrible, stunning blow accompanied by contraction of the muscles, so that having partially grasped a dangerous conductor and being in contact through some other part of his body with the other conductor of the circuit or with the earth, the unfortunate person would not be able to let go and the continued flow of the current through his body would result in death, just as sufficiently continued immersion drowns beyond the possibility of resuscitation. In this respect there is the greatest possible difference between grasping a wire, as described, and a mere shock, such as would be received by touching the conductor with the back of the hand which in that position could not be forced to grasp it; the resulting contraction would draw the hand away with probably no more injury than a severe burn.

Many electricians make it a rule when working upon or about a high tension dynamo to use one hand only, keeping the other behind the back, since the most deadly position in which to receive the current is from one hand through body and vital organs and out through the other hand to the return circuit.

Dry shoes and socks afford in themselves a great measure of protection, since being of insulating material they would oppose the escape of current through the feet to the ground, that is, to earth; while damp socks, a nail in the heel of the shoe and damp earth underfoot, would

afford a ready path to a high tension current and produce fatal results.

The man standing upon a dry non-metallic floor having on dry shoes and rubbers could not be killed by the most vicious current should he simply touch one of the wires conveying it, because his connection with any return conductor would be lacking, and it would be like pouring into a bottle as distinguished from pouring into a pipe with both ends open.

In a series of experiments made to determine the resistances of a human body, Mr. Edison finds that the grease and foreign matter with which the hands of the workmen examined by him were more or less coated, increased to a very great extent the resistance to the passage of an electric current into their bodies through their hands, affording fair protection against currents of moderate force in case of temporary and insufficient contact, as by a mere touch.

It is often assumed because a horse is killed by an electric current that the driver had a wonderful escape. Horses are very much more easily killed in this way than human beings; they have four contacts on the ground instead of two, and these, in a horse shod with iron, as is usually the case, make an excellent connection with the earth, and so enable more of a given current to pass through his body than would go through that of a human being. Then, too, an animal seems to be totally devoid of mental resistance, succumbing at once and hopelessly to a shock of any kind, and it seems to be altogether impossible to revive an unconscious horse with any means likely to be available in time. The passage of a powerful electric current through the human body for a short time,

even though accompanied with all the appearance of death, does not by any means necessarily result fatally. The writer knows an electrician, Mr. Frank Mayo, who has received through his body the full current of a dynamo-electric generator feeding a circuit of arc lamps at a pressure of 3,500 volts. He describes the result as the sensation of being struck a terrific blow with a stuffed club, then oblivion. This man would unquestionably have died had his comrades stood by and done nothing, allowing him to cool off and his blood to coagulate in his veins. But they went promptly to work and he soon revived and recovered entirely. The treatment in the case of an electric knock-out is precisely the same as in cases of apparent drowning. The body is kept warm, vigorously rubbed, and artificial respiration produced, if necessary, in the well-known manner by mechanical movements of the body. In almost all cases of this kind the stunning effect of the shock passes away in a few minutes and the patient survives. Of course he will need some quiet and rest, but he soon regains his normal condition without any permanent ill effect. In the instance referred to, the current was of the continuous type, which gives one tremendous blow, actual death resulting either when the current continues to flow through the body for a sufficient time to exhaust the capacity of the nervous system to react, or to produce chemical changes in the fluids therein which are necessarily fatal; or when, from lack of assistance, the temperature of the body falls too low before reaction takes place.

With alternating current, however, the case is different, because that current is composed, as we have seen, of a rapid succession of small currents, in regular commercial practice several thousand per minute, varying according

to the use for which the apparatus is designed. When these are of high tension a rapid succession of blows are dealt thereby which very quickly exhausts the recuperative power of the system and, aside from any other action, produces death.

Mr. Tesla says that when the frequency, that is, the number of alternations per minute, is run up to 100,000 or so, as has been done, the current becomes more like a tremor in the circuit and loses the deadly effect of lower frequency, as, say from 7,000 to 10,000 per minute; and that such current can be passed through the human body for several seconds at a time without danger to life and with the effect of a strong tonic. It is said that he takes this currency frequently as a bracer. Being on such familiar terms with alternating electric currents, Mr. Tesla is probably immune. As for the rest of us, well, we will take his word and believe him without trying it.

After most careful consideration, alternating currents from an ordinary commercial generator have been adopted by the State of New York as the means of legal execution of criminals. Official electrocution is carried out by placing the condemned in a chair insulated from the ground, connecting the hands and the head to the main conductors of the circuit, and then turning on an alternating current of sufficiently great force to instantly produce unconsciousness, the flow of current being continued until life is destroyed. The closest observation has established the fact that unconsciousness comes instantly; so that it is believed that this mode of execution is the most merciful yet devised. The apparatus being altogether out of sight, the unfortunate is spared the public exhibition of the ghastly preparations; and it is understood that the whole affair is over in a few minutes.

ELECTRIC RAILWAYS

THE electric railway in its most recent development includes three systems, known popularly as the "Trolley," the "Sub-Trolley," and the "Third Rail," in all of which the current which drives the motor upon the car is of the continuous type. Good, reliable, efficient, compact, and exceedingly convenient motors are now made, and, in general use, driven directly by alternating currents; but they are, with one or two exceptions, stationary motors having certain specified work to do. They are employed in mills and factories, and by the thousand for driving electric fans; but, for technical reasons, they are not best suited to the operation of electrically driven cars, carriages or wagons, due to the great variation in speed, power and control there required, as compared with the continuous-current motor, so that the continuous-current motor of the series type is used exclusively for these purposes. So great, however, is the economy of the alternating-current generator that on many large electric railways the current for operating the continuous-current motors thereon is originally generated by an alternating-current dynamo. This generator is sometimes located at a great distance from the railway to which the current is conveyed over conductors of comparatively small size and in a condition of high tension, great force, and correspondingly small quantity or volume. This current is transformed from its original condition, at points sufficiently near to where it is to be used, to a current of continuous direction and of lower potential and greater quantity. This is accomplished by means of what are called rotary transformers.

one form of which, previously known as a motor generator, consists of an alternating-current motor and a dynamo-electric generator mechanically connected so that the alternating current from the high tension supply circuit drives the motor and with it the generator. This generates and sends to the railway line continuous current of the desired potential just as though it were driven by a separate steam engine on the spot, but far more economically. The latest form of this apparatus will be further referred to in detail. In this way the power of a waterfall miles distant can be utilized for a long line, of railway, the alternating-current generator being located at the source of power—the waterfall—and operated by suitable water-wheels, and sending its current to the rotary transformers located at different points upon the line so that the current supplied directly thereto shall maintain a practically uniform tension throughout. The sections so supplied overlap sufficiently to give all the current that could be required at any point along the line to meet any unusual demand, as in case a large percentage of the whole number of trains were running at once and close together.

THE TROLLEY

The "trolley" is the popular name for the system of propelling street cars by electric motors which was the real pioneer that brought the subject before the public. This system demonstrated the capabilities of electric motors for transit and similar purposes, inaugurating a complete revolution in the means and methods of transportation, the ultimate extent of which can only be surmised.

As referred to in previous pages, some experimental

work had been done in this direction, but such difficulty had been encountered in conveying the current to the motors upon the cars that these previously tried plans have entirely disappeared. The system now in use is the invention of Chas. J. Van Depoele, a naturalized American citizen, who at the time was the head of an electric manufacturing establishment in Chicago, Illinois, and it was subsequently adopted by Mr. Frank J. Sprague of New York in his many important installations. Mr. Van Depoele exhibited a three-car train operating upon this system, at an exposition held at the city of New Orleans in the latter part of the year 1885, and the first commercial installation was in the city of Montgomery, Alabama, during the early part of the year 1887, sixteen motor cars running over fourteen miles of track being then and there in operation. With the trolley system, a street car provided with electric motors, connected to its wheels, is operated by the current taken from a bare copper "trolley wire," which is, however, well insulated from its supporting poles and arms, or poles and cross wires from which it is suspended above the track all along the line. This wire is connected to one pole of the generator and kept supplied with current of the continuous kind. Current from the trolley wire is conducted to the motors upon the cars through a grooved brass wheel, the ancient name of which is a "trolley." This practically new and easy word caught the ear of the public and was at once applied to the system.

The trolley wheel runs along the under side of the wire suspended overhead, and is supported at the upper end of a pole pivoted on the top of the car with springs at its lower end, which hold it up and press the trolley wheel

against its wire, thus making continuous contact with the current-supplying wire as the car moves along. In the simplest form of this arrangement one suspended wire only is used for each track, which is connected to and conveys the current from the generator. The rails of the track are electrically joined at their ends by copper bonds or bands securely riveted thereto. These bonds unite all the rails to form a continuous conductor, which is connected to the other or return side or pole of the generator. The current taken from the suspended wire passes, by way of the trolley wheel, down through the pole, or a wire attached thereto, through the regulating devices which are controlled by the motorman, through the motors operating them, and then by a connection, from the motors to the axles and wheels of the car, from which it passes to the rails of the track and so back to the generator, completing the circuit. The car with its trolley wheels and motors is thus placed between two conductors, just as is an incandescent lamp between its conductors, and by manipulation of the current-controlling mechanism the motorman allows more or less current to flow from the upper conductor down through the trolley wheel, the wire carried by the trolley pole, the regulating mechanism and the motors for driving the car, from which it passes by way of the wheels to the rails and back to the generator. This is the simplest form of electric railway in use, having proved mechanically superior to its predecessors, and also entirely successful in operation, while at the same time the most economical of all systems in cost of installation. It therefore soon appealed to capital as being speedier as well as cheaper in operation than any other known motive power, and very soon convinced the public of its capacity

and overwhelming success and so went into what is now practically universal use in this country, the United States.

The trolley has some objections, and much has been said about the effect of the return current escaping from the rails, passing to the earth and causing damage to subterranean pipes. In one city, Cincinnati, Ohio, a complete double set of conductors was placed overhead, and the trolley pole provided with two separate contact wheels or two separate trolley poles arranged side by side, so that the current in that system never gets to the ground at all. But thousands of miles of trolley roads have been built and many thousands more will be built in places and on roads where there are no pipes to be injured, and where no other system of transportation of equal capacity as compared with the original cost and subsequent expense of maintenance and operation, could be provided in any other known manner. In many cases where more expensive systems would perhaps never be installed at all, the introduction of the trolley and the utilization of wasted waterfalls or cheap fuel will, by introducing a supply of electric current into a community for lighting and power uses, lead to other and further developments, build industries now impossible, and so lead to material economy, advancement, and advantage, such as is now unknown except in a few favored localities.

SUB-TROLLEY

THIS system, which is a refinement of the original trolley system, consists in placing two conductors in a trough or conduit below the surface of the roadway and forming a continuous slot, or opening, level with the roadway above

them. These conductors constitute the outgoing and return paths for the current, are mounted in the troughs on thoroughly insulated supports about six inches apart on its opposite sides, so that a flat plate extending downward from the car and provided with a contact shoe on each side can engage their opposite faces. The regulating devices and the motors upon the car are exactly the same as in the overhead trolley system, the only difference between the systems being that, with the sub-trolley the current is taken from and returned to the conductors in the conduit below the surface instead of from a conductor suspended above the car. In this manner all objection is obviated, the conductors are out of sight, and, there being two complete circuits, each well insulated, there is no chance for the current to escape to the earth and injure subterranean pipes. This is the system exclusively in use in the cities of New York and Washington, D. C., and will undoubtedly supersede the overhead conductor system in other places whenever the enormous expense entailed in the sub-trolley construction is warranted or demanded by local conditions. As to its successful operation, there is no room for doubt.

THIRD RAIL SYSTEM

The third rail system, as generally understood, is intended for use where the line of the railway is not travelled over or used as are streets and highways. Such, for example, as the elevated railways of New York and Chicago, and the correspondingly isolated underground or tunnel railways of London.

In these systems one or both of the track rails is utilized as a return conductor, and the third rail, mounted

upon insulated supports, is located alongside of the track so as to be within convenient reach of a contact shoe, which is simply a piece of cast-iron attached to a spring secured to one of the trucks of the motor car and running on the top of this extra rail. The third rail is usually similar to the others, is placed at about the same height, and the end of each piece is connected to the succeeding one by copper bonds or bands riveted fast in holes bored therein for the purpose. Iron is not as good a conductor as copper, having only one-seventh of its conducting capacity, but an ordinary rail is of such size as to form an ample conductor, its material is so strong that the cast-iron shoe may rub along its upper side for years without damage, and again, the rail is provided with a broad flat base by which it may easily be secured in position, so that it constitutes the simplest and also the best means of constructing a conductor that has been found.

These third rails follow the track and are laid at a fixed distance, about a foot from the rails, all along the line. Where it is impossible to put the third rail on one side on account of a switch, a frog, or a branch track, a piece of third rail is placed upon the opposite side and electrically connected to the discontinued portions. The tracks are provided with contact shoes on each side, so that the train need never be, even for a moment, beyond the motorman's control for lack of current. The method of supplying current to the third rail does not differ in any important manner from that by which the trolley and sub-trolley are supplied, nor is there any substantial difference in the construction of the motors or their operation from the other two systems. In referring to the third rail system, the public should understand that larger and

heavier cars are used than on street railways, and that trains of cars are to be operated, the railways being to all intents and purposes the same as previously operated by steam engines, which they frequently displace.

Many different methods of controlling electrically propelled trains of cars have been proposed, and several have been tried, the most obvious being to equip the front cars with motors powerful enough to pull the whole train in place of the steam engine. This is the essence of simplicity, and two electric locomotives have been in regular use for several years hauling the heaviest trains, both freight and passenger, through the Baltimore & Ohio tunnel in Baltimore. However, in some special installations, as the elevated railways, the strength of the structure is the important feature which must be considered first, last, and all the time, and the question is how to operate the longest trains at the greatest speed without overloading the structure or rendering the cars difficult of control. The greatest attention is, therefore, being given to the question of how to start the train easily and attain the highest permissible speed in the shortest possible time, and this is secured by placing motors upon several of the cars of a train and thereby avoiding the accumulation of excessive weight in any one place. Obviously, it would be difficult to secure unanimous action on the part of a number of motormen separated from one another, so the most modern solution of this difficulty is to connect the conductors of all the motors so as to bring them under simultaneous control from a single point. This has been accomplished by the admirable system of Mr. Frank J. Sprague, now in operation on the Chicago elevated railways. According to this system the length of the train

makes no difference, because the longer the train the more motors there are. It can be operated at any point, and after the starting signal has been given and the current turned on, all of the motors, moving in unison, bring the train to its maximum speed in as short a time as could one large and powerful locomotive, the mere weight of which, aside from its draw-bar pull, would be sufficient to wreck the structure and bring it to the ground.

In tunnels, where the hot gases and cinders rushing back in a confined space make it necessary to close car windows and ventilators even in the most stifling weather, the electric motor is especially to be preferred. Here there is no limit of weight to be considered; and an electric locomotive attached to one end of the train, and sufficiently powerful for all purposes, can readily be used. This is preferred where no mechanical objection exists, because the mechanism to be operated, controlled, inspected and kept in order, is concentrated in a few locomotives instead of being subdivided and attached to a relatively large number of cars.

In this third rail system the track rails need not be particularly insulated, merely connected at their ends, as they are used only to carry the current away from the motors back to the generator after it has done all the work of which it is capable. A return conductor of some kind must be furnished so as to form a complete circuit, and this is essential under all conditions. It is sufficient if one of the two necessary conductors is insulated so efficiently that the current cannot escape therefrom except as it is permitted to do so through the motors to be operated. All care in insulation is bestowed upon the third rail, which is mounted upon very strong porcelain supports,

themselves sustained upon rigid stems or pins attached to the adjacent framework. The third rail can of course be and often is placed in the middle of the track between the ordinary rails, but with such arrangement it must be carried under switches or crossing tracks in order that it be continuous. In such cases, parts of the conductor would be out of reach of the forward contact shoe in crossing switches, and under these conditions the car is either carried over the breaks by previously acquired momentum, or, by providing a shoe at each end of the car, one or other of them would be always resting upon the conductor, the breaks being always less in extent than the length of the motor car. This system is exceedingly simple, strong, durable, and economical in construction and maintenance. The current-carrying conductor is strong and little liable to damage or accident, and all three of the rails being in the best position for examination, any fault or flaw can be readily discovered and corrected. In fact, the only disadvantage of this system is that it cannot safely be employed in connection with general traffic where people and animals pass along and over it, because of the danger to life from accidental shock, and the danger to the system of its being maliciously rendered temporarily inoperative by connecting the third rail with the return conductors, as, for instance, by laying a bar of iron across them. This, by giving a short direct path to the current from the third rail back to the generator without encountering the resistance of the motor, would divert an immense flow of current suddenly away from the rest of the line, creating what is known as a short circuit. Such an occurrence not only deprives the motors upon the cars of the current necessary to operate them, but in many instances results in serious damage to

the generator by returning to it suddenly an immense volume of current, which, unless very quickly discovered and cut off, would overheat its wires to such an extent as to burn their insulating coverings and render the machine useless.

The permanent generating or power station for the Metropolitan Street Railway system of New York City will, when completed, comprise eleven monster dynamo electric generators, each capable of producing electric current of the equivalent of 7,000 horsepower. These machines are of the engine type, that is to say, the two ends of the shafts carrying the rotating element of the dynamo-electric generator are connected to the piston-rods of the engine by which they are directly driven without the interposition of belts or gear of any sort. These generators run at the lowest speed for which dynamo-electric generators have been designed, viz., seventy-five revolutions per minute, and this is possible on account of the enormous size of the generator, which, at this rate of revolution, gives a sufficient peripheral speed to the moving part. The steam engines to drive these dynamos are of the very latest type; inverted, vertical, compound two cylinder. Some idea of the gigantic size of this apparatus can be gained from the fact that they are practically three stories high. The power house for these big engines is located near the East River and Ninety-second Street, where an abundance of water can be obtained for use in the condensers, and where coal is brought in barges direct to the bunkers at the minimum expense. The current generated in these large machines and sent out from the station will be of high tension and of the alternating type. It will pass over relatively small conductors to sub-stations

located in different parts of the city along the lines of tracks. At each sub-station will be one or more rotary convertors, which will receive the high-tension alternating current and straighten it; that is, will change it into continuous current, and at the same time reduce its potential or force to the point required for use by the motors on the cars by which said cars are propelled.

In the installation of a gigantic plant like this one, where a few enormous generators, or *large units*, as they are called, are employed to produce the vast volumes of current necessary for the simultaneous moving of hundreds of heavy cars, there must necessarily be a large amount of detail, and much ingenious work, to prevent loss by leakage and accident. Also, in order to know that the current being generated is of the proper character and potential, indicators have to be provided, and the whole network of conductors is divided into sections supplied by feeders, so that the pressure of the current may be equalized as nearly as possible throughout the entire system, including even the most distant portions thereof. The electrical art has, however, at the present time fully reached the point where all these details are provided for in the fullest and most thorough manner possible. Yet a detailed account of the special features of construction would require a book in themselves. They are therefore omitted except for the statement that the most elaborate precautions are taken to protect the apparatus against the effects of short circuits between the conductors or of accidental ground connections and of lightning discharges. Most carefully designed cut-out switches are also provided, by which the circuits in the power house may be opened and the combinations changed when it is necessary to di-

vert the flow of current from one point to another or to cut out a damaged section; or to isolate a section when from any cause it is desired to stop the flow of current, as when a big fire or some serious trouble is taking place.

In case of a small generator, say of 100 horsepower, it is quite possible to open the main circuit through a well constructed circuit breaker, of which there are now many standard types, without much of an electrical display beyond a few sparks. In the case of a circuit breaker carrying the enormous current produced by such generators as herein referred to, the difficulty is increased to such an extent that no ordinary apparatus could be used, for on attempting to open a circuit through the best circuit breaker in ordinary use, such an enormous flame (arc) would be developed that the switch apparatus would be instantly melted, and if there were any woodwork in the vicinity it would be set on fire. Furthermore, the man who started that kind of trouble would be fortunate indeed were he to escape with his life, for an electric burn is just as bad as any other burn, and worse in that it would be received swiftly and suddenly, and is much more likely to prove fatal than any electric shock. The burn would be the same as from any other equivalent flame, but, coming so quickly as it would under the circumstances suggested, there would be no escape for any one within reach. An accident of this sort, only on a much smaller scale, occurred in London a few years ago, when an inexperienced employee undertook to open a high tension circuit carrying a heavy current. The resultant flame (arc) was so terrifying that he ran for his life, leaving the apparatus to take care of itself.

The big circuit breakers provided for the Metropolitan system are not only specially contrived, but they are inclosed in tanks of oil, which, being a very good insulating material, interposes itself immediately that the parts are separated and prevents the establishment of an arc and so renders it possible to open the circuit without danger.

In the case of a system of electric railways so extensive and so complex as that of the Metropolitan system in New York City, it becomes necessary to supply the current to the exposed conductors in the conduit at a great many points. The exposed conductors are the metal bars from which the travelling contacts carried by the cars gather current to supply the motors as the cars pass along. Connection is made with these conductors at many points in order to equalize the potential or pressure, so that all the cars may be run at the same speed, and also that there will be plenty of conductors to carry forward the excess of current to any particular point to supply the excessive demand that would arise in case a number of cars should become *bunched*, that is, grouped close together, in one locality. There is another reason also for supplying current to the metal bars in the conduit at numerous points, and that is, that in case of a persistent short circuit at any point causing great loss of current there, or in case of an accident to a car whereby the track or conductors in the conduit are damaged, or in case of a fire or obstruction, a short piece of the system, including the break, may be cut out, all other portions of the system continuing to be supplied as usual, and the stoppage, if any, thereby localized, and the delay or inconvenience reduced to the minimum. The electric motors, generators, switches, etc., for this, the largest system now in actual operation, were de-

signed, constructed, and put in operation by the General Electric Company.

The Manhattan Elevated Railway lines of New York City are now being equipped for electrical operation, on the third rail system, the apparatus being supplied by the Westinghouse Electric Company. The equipment of a system of this magnitude—there being three separate lines extending the entire length of Manhattan Island—naturally takes considerable time and much work has to be done before anything appears that the public can appreciate. For instance, steam engines have to be constructed even larger than any which have preceded them. Generators have to be made which will secure the very best results as to steadiness of operation, reliability and economy under the conditions to be met; then, a power house has to be built to receive these huge machines, with extra strong separate foundations for each engine set, and a complete provision for the receiving, handling, and distribution of enormous quantities of fuel and the removal of waste products. When it is remembered that this power house must supply current which will develop power in motors miles away, to the equivalent of several hundred steam locomotives, the magnitude of the undertaking will be appreciated. The steam engines used in the Manhattan power house, of which there will be several, will each, it is said, develop 15,000 horsepower, with full steam admission. They will be of the compound type, with the generator between them, the piston-rods connecting with cranks upon the opposite ends of the generator shafts. These generators will also be so designed that the full maximum current will be produced with a rotation of the generator-shafts of only seventy-five turns per minute.

The power house now building is located upon the Harlem River and will be provided with several known and some unknown appliances for the protection of life, and for the safety of the apparatus, and with machines of such magnitude this is no small matter, yet it is absolutely necessary to provide efficient safeguards in every direction, and to meet every imaginable emergency. The systems of cables by which the currents will be carried from the power house to the different lines of railway and to different portions of the lines, will conform to the very latest modern practice in the matter of high insulation and careful design as to size and weight of conductors. The current as originally generated will be at a moderately high tension, which will be reduced by convertors at special stations in the different parts of the city, and it is understood that in addition to propelling the trains for the transportation of passengers, the company will use its own current for lighting all stations and signals, and for operating elevators at those of the stations to which it may be decided to lift the passengers from street to platform. It is also understood that there will be a motor car at each end of each train during the rush hours, when the line is worked to its full capacity, so that the trains may be reversed and sent back over the road with the least possible delay and without re-making the trains, which, with an elevated construction, is a consideration of the utmost importance. It is also fair to suppose that the company will produce just a little more current than is actually needed, in case some one conveniently located to the route should insist on being supplied therewith—for a consideration.

The requirements of high insulation, according to mod-

ern practice, are now so well known that whatever difference there may be between the particular features of the construction of the switches, cut-outs, rotary convertors, etc., in the Manhattan Railway equipment will be only differences of detail over that just referred to in connection with the Metropolitan Railway of New York City.

SPEED

MUCH has been said concerning the speed at which electric railway trains, cars, or vehicles can be propelled, and this subject is one of great interest, partly because with increased use of the telegraph and the telephone, naturally comes a demand for increased rapidity of personal communication. As the business portions of our cities become more occupied by mercantile establishments, the population is forced further and further to the suburbs, and the question of rapid transportation from home to business is of the utmost importance to all city workers.

Rapid transit is a relative term both as to distance and in connection with the numbers to be transported. Time was when the horse car was rapid transit, yet to-day, with the trolley car running at four times the speed, it is counted too slow, and that only because of the greater distances at which people expect to live from the scene of their daily occupation. There is now little doubt that the rate of speed at which surface cars can be safely operated in cities has been attained, if not exceeded. We hear every now and then that a new line is to be constructed between some two large cities, on which the rate of travel is to be one hundred miles an hour by electric motor, and the public seems to have acquired the conviction that the

transportation experts are looking for a machine that is capable of attaining this speed, entirely ignoring the question of track construction, grades to be overcome, curves to be traversed and the like. In other words, the public assumes that the prime motor is the only thing to be considered.

The electric motor, whether in the form of a locomotive at the head of the train or a number of separate motors distributed under the different cars composing the train, has an advantage over the steam locomotive because the moving part, the armature, of the electric motor has a rotary motion which is communicated directly to the wheels to be driven. As long as current is furnished, the armature tends to drive the wheels continuously in the same direction. There is no difference in the direction of the force supplied, so long as the current is on. Now, with the locomotive, good as it undoubtedly is, the movement is communicated to the driving wheels from pistons which move back and forth in their cylinders, one on each side of the engine, and in reality the pull of the locomotive is first on one side and then on the other, and when the locomotive is pulling a train, the tip of the cowcatcher can be seen to have a short, quick, zigzag motion across the track. This is called *nosing*, because it resembles the motion of an animal, particularly a hog, hunting for something on the ground by means of its sense of smell. When it is considered that the pistons of the locomotive reciprocate sometimes as rapidly as 400 times per minute, and that with these reciprocations the piston must come to a dead stop before starting in the opposite direction, the rack and strain upon all parts of the machine will be apparent. Locomotives have run at the rate of more than

100 miles an hour for short distances, and with the knowledge now available they could be built to exceed even that speed, but the risks of running a train at the rate of 100 miles an hour, for an hour, would be altogether too great for regular travel under existing conditions. This speed has been attained on special occasions, but only upon short selected portions of the best railways, as they are at present constructed—that is, with tracks practically on the surface, and the cars and engines having single-flanged wheels, the principal difference over surface city tracks being that the regular steam roads have easier grades and curves.

The electric motor is undoubtedly better fitted for the attainment of high speed than the steam locomotive, because of the entire absence of reciprocating parts and the consequent wear and tear upon the machine; but this advantage of construction would not make it safe to operate a train electrically at the rate of 100 miles an hour, except upon an ideal track such as does not now exist. The first requirement of this track would be that it be straight, and the next that it be constructed in the most solid and substantial manner possible. On such a road grades would be of less importance than curves, because with sufficient power grades could be climbed at full speed, but the tendency of a train to run off the track on a curve is always present. Moreover, at very high speeds, it would be of vital importance that the engineer should be able to see the signals far enough ahead to be able to stop when necessary without tearing the train to pieces in overcoming its momentum, for the result of even a small accident at such high speed could not but be disastrous.

It has frequently been proposed to construct a high-speed passenger railway of a new form, in which a single

rail is carried upon continuous trestle work at a sufficient height above the ground—some fourteen feet or more—and upon which specially constructed cars would run, the cars straddling the track. It is claimed that in this way derailment would be prevented and any desired speed could be attained without danger, since the track would be entirely free from crossings or interference of any kind, and with cars of narrow construction, so as to afford the smallest wind resistance, that great speed could be attained and maintained with safety.

There is no doubt that higher speeds will be attained in the future, but I am of the opinion that it will be in connection with some special form of track, and be largely limited to the carrying of passengers, mail, and the high class of express matter. It remains to be seen whether such a railway will be sufficiently patronized, at higher prices than those now paid, to warrant its construction; because it must be remembered that the existing advantages of through cars to distant points, connections from one railway to another, the transfer of baggage, etc., in bulk, would all be lost until such systems were universally adopted.

NEW YORK AND CHICAGO ELECTRIC RAILWAY

THERE is at the present time in existence a company organized for the purpose of constructing an air-line railway from New York to Chicago. This road is to have an elevated and specially designed track just high enough above the ground to permit surface traffic to pass under it. This would ordinarily keep the line free from snow block-

ades, and of course it would be raised higher where necessary, in order to pass over depressions, valleys, rivers, and the like, at a sufficiently easy grade. The cars are also to be of special design—as small and light as possible consistent with necessary strength. The trains are to be short and run at frequent intervals at a steady speed of 100 miles per hour. This would reduce the time from New York to Chicago to nine hours instead of the twenty-four now required by the fastest train running between the two cities. This company has been in existence about three years, during which time the plans of construction have been worked out to the minutest detail, and it is said that the money necessary for the construction will be forthcoming in a short time.

It is estimated that it will take only two years to build the road, allowing another year for the perfection of details of operation. It is intended to extend this form of railway all over the country, but the public will await with the greatest interest the completion of the first section of track. It is intended to carry freight of all kinds as well as passengers, although very naturally preference will be given to express matter and perishable goods up to the full limit of capacity. One feature of such a railway as this is that the two through tracks intended for the highest speed could not carry local business and trains running short distances under any circumstances. All the trains would be express trains, making only four stops between New York and Chicago.

Upon reflection it will be apparent that trains running at such a terrific speed must be protected in the fullest possible manner by block signals and every safety device known to the railway art in order to prevent rear-end col-

lisions, and that no trains must be allowed upon the track under any circumstances which could by any possibility get in the way of a flyer. With arrangements of this sort in a perfect state of operation, light, swift trains could be run every thirty minutes, but, of course, in order to maintain such a schedule, they would all have to run at the same rate of speed. Consequently, freight, passenger and mail trains would have to be made up so as to be substantially alike both in form and in weight, and this would very greatly simplify the operation of the entire system.

As steam railroads are at present operated, trains are run at all sorts of different speeds, and an express train, on a long line, has to dodge in and out between slow local trains, as well as freight trains, so that all trains are under the constant surveillance of the train despatcher, who must know where they all are and keep himself informed of their movements. With this high speed, however, all trains would have to move at the same rate and would be alike to him, and it would be merely a question of keeping them a proper distance apart to avoid danger of rear-end collisions. This, under such circumstances, would be so simplified that an absolute block system, which deprived a following train of current to propel it when entering a fresh section until the train in advance had left the section, would effectually prevent this danger. Of course it follows that with such a railway local trains would have to be provided with separate local tracks upon which a much lower speed would be maintained, but when one is travelling from ten to fifty miles only, a come down from one hundred miles an hour to, say, fifty, would, even at that, transport the short-ride passengers at speeds far beyond anything ordinarily attainable at the present time.

EVOLUTION OF THE MODERN DYNAMO-ELECTRIC GENERATOR

IN THE early days dynamo-electric generators, supplying current for the largest stations, were in the form of small machines, of which a number, sometimes as many as a hundred, were employed in a single power house. These machines were driven at very high speed in order to produce the desired results, and this speed was attained, as in any ordinary mechanical arrangement, by connecting the fly-wheel of one large engine to suitable shafting carrying pulleys, and connecting the armature shafts of the dynamo to the pulleys on the driving-shaft. In that way the slow-running, old-fashioned engine could be made to drive the generators at the desired velocity. This plan, however, was subject to the very great disadvantage, that the driving of the pulleys, belts and shafting necessary to secure these results absorbed a very large percentage of the power of the engine, and belts will slip, pulleys get loose, shaft bearings become hot, and all require constant attention. It was next sought to accomplish the same results, but in a more economical manner, by constructing engines which in themselves were capable of running at an exceedingly high speed, and connecting them direct, by belts from their fly-wheels, to the pulleys on the armature shafts of the dynamo, thus eliminating the shafting and counter-shafting and in many instances clutches, which were necessary when it was desired to disconnect one or more of the generators during different parts of the day. This plan also had its disadvantages, and it began to be generally appreciated that the speed with which electric

generators were run must be lowered, in order that the mechanical strain should be diminished and greater economy and certainty of operation result. With the development of the electric railway came larger demands for electric power than had ever before been known, and the size of the generators then began to grow, so that now, instead of providing ten or twelve generators, that ten years ago would have been considered large ones, to supply the current for a system, big machines are constructed, each one of which is connected directly to the most economical type of steam engine that has yet been produced. This is the vertical, inverted, multiple-cylinder compound engine, the dynamo-electric generator being in the centre between the main supports of the engine. Above and on each side of the generator are cylinders of the engine, the piston-rods of which are connected directly one to each end of the armature shaft of the generator, so that said armature, or it may be a revolving field-magnet instead, operates as the fly-wheel of the steam engine and the moving part of the generator. All forms of belting, shafting or gearing are entirely eliminated, and by centralizing many machines into one, that one can be made of such a size that a slow rotation of its enormous armature will give the same peripheral speed, and the same generating effect, as the high velocity with which it was necessary to rotate the little *armatures* in the early days to produce the same results.

The early machines used to be operated at speeds of from 1,800 to 3,000 revolutions of the armature per minute, which was obtainable, but only at constant risk of breakdown. The enormous, direct-driven, engine-type dynamo-electric generators of the present day are, many

of them, operated at a speed of rotation of only seventy-five revolutions per minute. The difference is very suggestive of the advances that have been made both in comprehension and construction.

ALTERNATING-CURRENT GENERATORS

These generators were the first ones to be regularly employed in the earlier days of the electrical art, and it is true that as early as 1860 a magneto-electric generator was employed to operate an arc light in a lighthouse on the French coast. There alternating-current generators were made, but although they were simple enough, the utilization of the currents gave the electrician so much trouble that upon the appearance of the Gramme machine —which was the first commercially practical continuous-current generator—the alternating-current generators were condemned and banished to the scrap heap, because the pioneer (embryo) electricians had altogether too much on their minds. Just as soon as unlimited supplies of continuous current became available at a possible cost, they succeeded in producing continuous-current automatic arc lamps, which made a good showing and brought the matter favorably to the notice of the public. Continuous-current generators, arc lamps and motors seem to be covered by such simple laws, that for some ten years apparently no notice was taken of the alternating-current system. True, the commutator, by which the electric current was straightened, was costly to construct and to keep in order, but it was easier to do this than to cope with the metaphysics of the alternating current. So it came about that

for many years the alternating current was regarded as a dangerous and impracticable form, and, so long as the continuous current met all requirements, it controlled the field. The original alternating-current generators were entirely supplanted by the continuous-current generators of Gramme, Siemens, Brush, Thompson, Edison and others. These conditions prevailed for a number of years, as long, in fact, as the use of electricity was practically confined to systems of lighting in which the current would be generated in a central station, located as near as possible to the centre of the system of distribution, and sent out in different directions for a few miles.

It is true that some of the forms of continuous-current generator constructed for this purpose have been able, through their special commutator provisions, to attain a high enough voltage to force a small current over a circuit many miles in length. These machines are, however, neither economical, durable, nor safe for any purpose except the special one for which they were constructed, namely, that of operating arc lamps, and the limitation of the pressure at which current can be generated in a continuous-current dynamo is found in the commutator. While it may be possible to generate continuous current, straighten it through a commutator, and deliver it twenty miles from the generator at a pressure of 5,000 volts, this would be exceedingly difficult; whereas with an alternating-current generator, which, as we have seen, has no commutator, merely collecting rings connected to the generating coils, a current of 5,000 volts can be readily undertaken, and by means of a static transformer it can be stepped up to 20,000 volts, and has been so raised to 50,000 volts, when it can be sent one hundred miles and more without

material loss. It may as well be confessed here that a pressure of 50,000 volts is more than any one would at present care to be intimately associated with, there being a new set of troubles to consider and new problems to solve when such high pressures are attained.

The situation to-day, therefore, is, that for all long-distance high-pressure work, the alternating-current generator is the only one to be considered; and this machine is now so thoroughly understood, both as to the laws of its construction and the method of its operation, that the largest installation can be undertaken with entire safety and with a correct anticipation of the results to follow.

Renewal of interest in the entire subject of alternating currents, their generation, distribution and utilization, immediately followed the discovery by Messrs. Gaulard & Gibbs of London, about 1883, that the induction coil was reversible. The induction coil is often referred to as the Ruhmkorff coil. This apparatus has been, and is, much used, as it affords the means of obtaining large electric sparks from the discharge of electric currents of enormously high pressure between separated terminals, the original source of current being an ordinary galvanic battery. The apparatus comprises a subdivided iron core, usually a bundle of wires. Upon this core is wound a coil of thick wire. The terminals of this wire are connected to the opposite poles of a galvanic battery containing any desired number of cells, and an interrupter is placed in the circuit, which interrupter may be operated by hand or be automatic. Over this first or primary coil is then wound a much longer coil of small wire, the terminals of which can be brought to adjustable polished spheres for

the purpose of producing sparks by discharges between them, or connected to any circuit which it is desired to supply with alternating currents of high tension. Every time a current flows in the primary circuit, a current will be induced in the secondary which is over it, and when the current stops in the primary, another current will be induced in the secondary. Consequently, when the battery circuit is closed and the automatic interrupter is in operation—and its operation may be inconceivably rapid—the makes and breaks in the primary circuit will be so fast as to produce an exceedingly rapid succession of alternating currents of far higher tension in the secondary.

Gaulard & Gibbs published the fact that by connecting the terminals of an alternating-current dynamo to the primary circuit, it would act to produce currents in the secondary just as though the battery and automatic interrupter were used. This enabled them to produce continuously the high-tension alternating current from a low-tension alternating dynamo. They also discovered, and made public the fact, that when the current of a high-tension alternating-current generator was sent through the secondary or high-tension coil, it would react upon the primary, just as the primary had previously reacted upon the secondary, with the very important difference, however, that, by this reversal, the alternating current, coming from what was previously the primary of the induction coil, was reduced in potential, while increased in quantity, in exact proportion to the difference between the windings. They also utilize this discovery by applying the reduced high-tension current so produced to a system of incandescent lighting having high-tension distribution with local reduction for consumption circuits, as it had

been found out that the incandescent lamp, although made for use in continuous-current circuits, would operate equally well with alternating current, provided, of course, that the alternations were so rapid as not to be perceptible to the eye.

Immediately after these facts became generally known, investigation and experiment began, and, starting with knowledge gained from ten years' actual, practical and far-searching experience with continuous-current apparatus of all kinds, it was not long before alternating-current systems of electric lighting were developed and largely introduced, continuing to be, ever since, not only a competitor of the continuous-current systems, but proving to be much more economical where the territory to be covered is extensive.

With the advent of the electric railway and the demands for vast volumes of current, came the natural consideration of the utilization of waterfalls at long distances from the work to be performed. Obviously, it would not be practical from the standpoint of commercial economy to carry the current over such distances at the pressure which has been adopted for use on all electric railways, namely, 500 volts. Very soon it was found that alternating-current generators could be constructed which would deliver current at a pressure of many thousand volts without committing suicide, and that such generators could be employed to convert the power of the waterfalls into electricity which could then be economically conveyed to the vicinity of use. Thus it came about that electricians returned to the original form of mechanically produced current, but with all the experience of the intervening years, so that it is now really only necessary to understand the

physical conditions, when the electrical engineer is prepared to meet the demand, whatever it may be.

ALTERNATING-CURRENT MOTORS

THESE motors are especially adapted for use in circuits carrying single phase or polyphase currents, and the refinements of construction have gone so far that motors are especially adapted not only to circuits supplied with alternating currents of different character, but to be operated at their best with currents of stated frequency. So far has development extended, that a motor, constructed to operate upon a circuit supplied with currents which alternate at the rate of twenty-five cycles per second, works at its best with such current, while the motor designed for a circuit in which the frequency of alternation is sixty cycles per second will operate at its most efficient rate when supplied with such current rather than with a current having a greater or less frequency of alternation. This is mentioned merely to indicate the degree of advancement in this branch of the art, which at the present time is far beyond the comprehension of any except those who make it a special study. Although, as hereinbefore mentioned, and as referred to in Chapter VIII., the earliest of the electric generating machines were of the alternating-current type, the gentleman who produced them would not have known what to do with the alternating-current motors of the present day, so utterly different are they from anything even dreamed of in those early times.

The development of the modern alternating-current system of transmission of power, including the large, high-tension generators, naturally led to great improve-

ments in means for raising the potential of the current when that was necessary in order to enable it to traverse extraordinary distances with only trifling loss, they being called step-up transformers, and in reducing the current at the receiving end by means of step-down transformers.

With this apparatus, however, whether step-up or step-down, the current retained its original characteristics, and, whatever its tension, was still an alternating current, having the same number of alternations per second as when it started from the generator.

During the supremacy of the continuous current, which may roughly be placed as including the period between the years 1879 and 1894, large numbers of continuous-current motors had been manufactured and put into service, also the electric motor had been applied to the propulsion of passenger-carrying vehicles, and the electrical railway had come into existence as a practical thing. It therefore became necessary to consider the conversion of alternating currents into continuous currents on a commercial scale. Furthermore, the series wound, continuous-current motor remains to-day the most desirable machine for converting electrical energy into mechanical power upon a travelling vehicle, so that the conversion of large volumes of alternating current into continuous current to supply electric railway lines, received early consideration, and this resulted in the production of the modern rotary transformer, the two types of transformer being known respectively as the static, which we have already considered as the analogy of the Ruhmkorff coil, and the rotary, now to be mentioned.

The modern rotary transformer is a most remarkable machine in every respect. It resembles a dynamo-electric

generator in having an armature and a field magnet, but differs therefrom in having an alternating-current generator, or motor rings, connected on one side to its armature coils, and a regular continuous-current generator, sectional, commutator connected on the other. This extraordinary machine is supplied with alternating current at double the tension of the continuous current that is required. Under the influence of this current the armature rotates, consuming a small proportion thereof, while the rest is straightened upon the commutator, its pressure cut down one-half, and delivered to the line as continuous current, the loss being only the small amount of current required to rotate the armature of the machine, plus the friction of the bearings. This would seem to be the absolute limit of economy, for in point of fact one single armature winding is made to perform two separate functions, more economically, and fully as well, as though two separate machines were employed to do the same work as had previously been done. As already stated, only a few years ago a rotary convertor, or motor generator, comprised an alternating-current motor armature, and a continuous-current generator armature, both upon the same shaft. The alternating supply current was led to the alternating motor armature which it drove, being entirely consumed in so doing. At the same time rotation of the generating armature generated a new continuous current which was sent to the line. As we have seen, the rotary convertor of the present day comprises only one winding, which is driven by a fraction of the alternating-current supply, the remainder finding its way therethrough and out through the commutator in the form of continuous current ready for use.

While this work relates primarily to the connection between electricity and modern life, it would be incomplete without a passing reference to the steam engine, and to the water-wheel, to the extent of stating that the dynamo-electric generator has done more for the steam engine and the water wheel than any other agency whatever. This may seem paradoxical, but it is a fact that, until the advent of the steam-driven electric generator, there was no demand for that close automatic regulation of the steam engine which now exists. Many of the early failures in electric lighting plants which were charged up to the electrical apparatus were absolutely and wholly due to the prime motor, the steam engine. There is no doubt that electric generators have greatly improved also in the meantime; but the simplest dynamo-electric generator of the early days, of either type, Pacinotti or Gramme, was infinitely superior to and more efficient than the best steam engine of that time; and as to water-wheels, for many years after the introduction of the dynamo-electric generator and the consequent enormous burst of development in the electric art, they remained such an uncertain quantity, and their means of regulation to meet fluctuations of load on the generator were so crude and inadequate, that they were very little used. For a long time water-wheels were therefore not considered available as prime motors. Since then, however, mechanical engineers have given much attention to the question of their regulation and control, so that the various types of water-wheel of to-day afford a very practical and exceedingly valuable prime motor for electric generators.

ELECTRIC LIGHTING

THE automatic electric arc lamp has now been in public use for twenty years. This lamp apparently reached a state of perfect development ten years ago, as a steady, reliable and most powerful illuminant for outside use and for the economical lighting of large interior spaces. Arc lamps were always connected in series so that the current passed through them all in succession, each lamp consuming that portion for which it was adjusted. Arc lamps do not use a very large volume of current, but the resistance of the arc is considerable, so that with forty or fifty of them connected in series in a circuit including several miles of wire, the voltage, or pressure, of the current necessary to traverse the entire circuit is decidedly high. These lamps were each supplied with a pair of carbons, usually protected by a large open globe, the arc being freely exposed to the atmosphere. The carbons as ordinarily used would burn sixteen hours, and consequently they had to be renewed, and the lamps trimmed, as the term is, every day.

For several years it was expected that great improvements would be made in the construction of incandescent lamps, and that large sizes of that type of lamp would come into general use indoors. Large incandescent lamps have been on the market for many years and they are made to-day of 100 candle power or more, but they have not become popular, partly because of their cost, coupled with the fact that a damaged incandescent lamp, be the injury ever so slight, is altogether useless.

It is only a few years ago that the alternating current

began to be again applied generally to electric lighting; previous to that time, for many years, all electric lighting had been accomplished by continuous currents. The very early experiments, prior to 1880, had all been with alternating currents, which, being little understood, had not given good results, and were abandoned altogether for a number of years in favor of the continuous current, as produced by the machines of Gramme, Thompson, Brush, Edison and others.

Some seven years ago a type of arc lamp was introduced by the Westinghouse Company expressly for use in connection with their alternating-current system of electric lighting. This lamp had wide, flattened carbons which were consumed by the arc travelling backward and forward across their adjacent ends. These lamps would burn two nights or more without retrimming, but they were not equal in performance to the best continuous-current arc lamps then in existence and therefore have not survived. Doubtless such improvements could and would have been made as to render their service equal to that of other arc lamps, except that the shifting of the arc in travelling across the ends of the carbons would always cause a movement of the light that would be objectionable and unavoidable. About five years ago, however, an improvement was applied to the arc lamp generally, which is of such importance both to the electrician and to the public as to deserve special mention. The open arc lamp just referred to is mentioned in Chapter XV., and illustrated in one form in Fig. 67. The great step from that lamp to the neat and graceful device that can now be seen almost everywhere, marks an enormous improvement. The automatic regulating mechanism is contained in the upper metallic por-

tion, from which depends a large, flaring reflector, under which is seen a narrow, elongated globe secured at its base to the bottom of the frame, in which base the lower carbon is also secured. The upper part of this globe has a cover through which the upper carbon descends, the arc being formed within the globe, which, small though it is, has proved its capacity to resist and last indefinitely under the enormous heat generated in the arc within it. The globe excludes most of the air and these lamps are known as "inclosed arcs."

The extraordinary result of this apparently simple change—that of inclosing the arc in a practically air-tight globe—is that the life of the carbons is increased ten times, and even more; so that instead of arc lamps being trimmed every day, as with the old style open arcs, the inclosed arc will burn for as much as two hundred hours without trimming. This means that small and very economical arc lamps can be, and now are, made, which are well suited for use in moderate sized halls and interiors, and which, when trimmed, are hauled up into their positions where they do not require any further attention for two or three weeks according to the amount of use. This also reduces the cost of carbon and makes it practicable to use a higher grade which undoubtedly gives a better light. Moreover, the light from an inclosed arc lamp appears to be steadier and is undoubtedly much softer than that of the ordinary open arc; the heavy black shadows from the frame disappear, and the hissing and humming are done away with. These lamps are now made in the regular large sizes, and also in medium and very small sizes for interior use. Their length has been greatly reduced, and with the ornamentation that is now being ap-

plied to them the objections so long apparent with the regular arc lamps have almost entirely disappeared.

ARTIFICIAL DAYLIGHT

A NEW system of interior lighting which promises a great advance toward the ideal has been devised and brought to a state of practical public demonstration by Dr. D. McFarlan Moore of Newark, New Jersey. The incandescent electric lamp so largely in use is now a familiar object, and it is generally understood that the light given thereby is usually of a distinctly yellowish cast. The general public is also familiar with the arc lamp, and knows that its light is of a dazzling white, running to a steel blue in many instances, and that this is exceedingly trying to the eyes. Most people have been accustomed to oil lamps and gas, which long ago attained their highest degree of perfection, and upon the appearance of the modern arc and incandescent lamps it was generally thought that the art of illumination had reached its limit.

Mr. Moore, however, comes to the front with a further development in that art, offering to supply a light which he calls artificial daylight, and which is produced in the interior of long glass tubes which are to be secured about the cornices and corners of a room, around pillars in churches, upon the ceilings, and, in fact, wherever the best results will be produced. The light produced by this system is perhaps best described in the inventor's words as a beautiful milky glow which entirely fills the tubes, is pleasant to the eye, and diffuses throughout the room a beautiful white light. The principle of the apparatus employed is not that of the Geissler tube, which

at first sight it most nearly resembles, but consists of a vacuum vibrator, each tube being exhausted and provided with a terminal and with a wire extending from one terminal to the other, but capable of vibrating so as to make and break the circuit through the tube with great rapidity. This produces the peculiar light. Just what will be the outcome of this invention, in competition with the earlier systems, is of course a matter for the future to determine, but the light as exhibited is most attractive, and it may find a place of its own on account of its beauty of character, or ultimately develop such advantages, compared with mechanical disadvantages, as to compel its adoption in large new installations. Certainly the possibility of filling a room or hall with artificial daylight or sunshine entirely free from glare or noise is alluring, and it may be that Mr. Moore's invention may yet lend itself to some sort of new combination or modification that will bring it into early prominence.

AUTOMOBILES

THE past two years have seen a most wonderful growth in the application of electricity to the propulsion of motor vehicles in cities. These at present are in the form of cabs, carriages and delivery wagons, all of them being operated by storage batteries, which are carried upon the vehicles and renewed at central stations when necessary. The electric motor vehicle is no longer either a toy or an experiment, but by the efforts of skilled electrical engineers, combined with the courage of a few daring capitalists, the first cab station in New York, after existing for a year or more without attracting very much atten-

tion, sprang suddenly into public notice and favor. This brought unlimited capital to the aid of enterprise, and from this comparatively small beginning in New York, the industry has grown until sub-companies for operating electric vehicles have been organized in all, or almost all, of the large cities of this country. The occasion of the sudden direction of public attention to the usefulness and value of the electric cab was a severe and protracted snow-storm in the month of December, 1898, when very few vehicles of any kind whatever could be operated, and many stablemen refused to let their horses go out on account of the weather. Electric cabs, however, came to the rescue, and were operated day and night to their fullest possible extent. This naturally attracted attention, and, upon investigation, the amount of work performed by these cabs under such trying circumstances was found to have been prodigious, and they were thus brought at once into public favor, with the result that no amount of capital has been able up to the present time to supply the demand for this type of vehicle.

Notwithstanding the fact that a motor vehicle loaded with storage batteries is far heavier than an ordinary vehicle, and also somewhat heavier than the competing system of gasolene and steam operated carriages, the electric motor has an advantage as a driving agent that is not possessed by any other power. First of all, it is a rotary motor connected directly to the wheels. It gives forth no heat, no smell. It is not dependent upon sparking devices, or fire to be regulated, or water to be supplied. It stands still without a sound, and is ready at all times to move forward or backward, fast or slow, according to the will of the driver. Then again its motion is absolutely steady,

it has no dead points, and so long as the current lasts it is an ideal mode of conveyance. The large pneumatic tires used at the present time serve to absorb all jar and vibration, and make the vehicle comfortable to the passengers. The objection to the storage battery vehicle has always been that good reliable batteries are very heavy, and therefore are troublesome to remove for charging or to exchange for a charged set, but these difficulties have been all eliminated by Mr. G. Herbert Condict, who devised a mechanical arrangement for withdrawing a tray or set of spent batteries from a motor vehicle, and replacing it with a similar tray of fully charged batteries. So perfectly does this apparatus work, that from the time a cab is run into the station and its spent battery removed, to the time it can leave with a new set, and fully prepared for another tour of duty, need occupy less than three minutes. No number of men could handle these heavy trays of batteries in double the time, and the charging and loading and general care of the vehicles having been reduced to an organized system with known factors of cost and wear and tear, the electric transportation of passengers in cities by cabs of this type may be regarded as an established and assured success. Many private persons as well as physicians now rent these cabs for permanent use, having them constantly at call within a few minutes by use of the telephone. And so begins the exclusion of horses from cities, which, it is prophesied, will in this country occur within twenty years. Architects also are beginning to take cognizance of the automobile, and to consider planning for a room in the lower part of the house to accommodate it. Perhaps this is suggested by the bicycle, which to a greater or less extent seems to

cumber every hall in the country, and has to be, and is, definitely arranged and cared for in the construction of the larger office buildings in those parts of our large cities that are favorable for cycling.

While it is true that the electric automobile is helpless without current, it is also true, although not generally known, that any kind of current can be utilized in some way to charge the storage batteries by which it is propelled. Ordinarily the direct current used for interior electric lighting is just right for a storage battery, so that in nearly every city in this country the owner of such a carriage could charge it from conductors in his own house.

Mr. Condict's system provides automatic devices for indicating when the batteries are fully charged, and also for cutting off the current; so that it is now possible for one to have his electric automobile in a room provided therefor in the basement, connections run from the electric light wires in the house for charging the same, and after using the machine all day, to connect it to the charging circuit at night and leave it to take care of itself. This is simple enough, and will undoubtedly lead to the use of a vastly increased number of private vehicles in cities where the horse, although a noble animal, is now recognized as a nuisance, both in his stable and out of it, that must eventually go to pastures green, where he will be vastly better off, and the sanitary condition of our cities correspondingly improved. It is the horses' shoes that cut fine pavements, and there is no remedy for this except coarse pavements. Wheel tires can be made wider, but horses' hoofs cannot, and the dirt and litter due to them is the direct cause of the clouds of dust with which we are

afflicted. To eliminate all of these things will take time, but events move rapidly in this country, as can be seen from the enormous growth of the electric railway in the last ten years. Storage batteries can only be charged by the passage through, or rather into, them of a continuous current of the proper potential or force; but, as said, any kind of current can in some way be utilized for this purpose. A New Yorker, owning an electric automobile, desired to have it with him on his summer vacation in a village which is lighted by incandescent lamps using alternating current. He rented a stable and procured two pieces of apparatus which he arranged as transforming and charging plant. The alternating-current supply conductors were connected to an alternating-current motor, and the rotating part of this motor he connected by a driving belt through the rotating part of the ordinary continuous-current motor, which was driven mechanically by means of the alternating-current motor, and so the second motor was used as a generator. The current from this was conducted directly to the storage batteries without removing them from the vehicle. Transforming sets for changing alternating into continuous current are now made in which the parts are all mounted upon a single base, so that the machine, transported as a whole, can be set down anywhere, and needs no special foundations or alignment or adjustment. In fact, it is complete in itself, and ready for use on connecting the alternating end with the supply current, and the continuous-current circuit with the batteries to be supplied.

If the available current is of too high a tension and too small a quantity, this can also be rectified by passing it through a rotary transformer, as in the case of utilizing

similar currents purposely transported over long distances to the vicinity of use.

The public cabs are ordinarily provided with storage batteries sufficient to propel them thirty miles. The batteries are tall, narrow jars of vulcanite, each containing a number of leaden plates combined with a chemical substance. For convenience of handling, and also to prevent the jars from being loose and capable of rattling or shaking among themselves, they are arranged close together and tightly wedged into strong wooden trays of standard size, interchangeable, and weighing, complete, about 1,500 pounds. These are the trays which are handled with such great facility by loading and unloading mechanisms at the central station. In private vehicles, where it is desired to remove the batteries for charging, or to exchange them, they are arranged in smaller groups; and instead of being attached to the vehicle as a whole or placed in a single large space in the vehicle, they are stowed away in small closets, but all connected to a single controlling mechanism.

Where the storage battery when fully charged will carry sufficient current for the entire day's use to which the vehicle is likely to be put, the battery can, as we have seen, be charged at night and used during the day. It should be remembered that, as a general thing, a storage battery requires as much time for charging as for discharging, counting the discharging as the time during which the current is actually passing from the storage battery to the motor. If many stops or calls are made in the use of the vehicle, it might often be out the entire day and the battery be called upon for not more than four hours actual service altogether. In many cases, however,

it will be found much the best for the private user of an electric automobile to have on hand a duplicate set of batteries, with tray and contacts all complete, to be exchanged for the set on the vehicle whenever it is more convenient to do this than to take the time required for recharging. This is now quite practicable, for, notwithstanding the great weight of a standard tray of batteries, such as are handled by the machinery at the central station, mechanism has been devised for private use, whereby the sets of batteries can be exchanged by one man without difficulty and in a comparatively short time.

TELEGRAPHY

MANY plans for sending large numbers of telegraphic messages with great rapidity and absolute accuracy have been proposed and developed during the past few years, and are now in a state of readiness for adoption. It has been recently proposed to use the telegraph to literally send carloads of messages between certain large cities. One of the latest propositions, which is undoubtedly practicable, and must eventually go into use, is to avoid physically transporting the tons of letters that daily pass between such cities, for instance, as New York and Chicago, requiring thirty-six hours in transit.

It is assumed that most business letters can be expressed in fifty words or under, and it is proposed that the copy for these letters be mailed in the usual way, collected, and opened at the post-office. Then that the contents be transcribed on a machine resembling a typewriter, which produces a continuous perforated strip of paper similar to that referred to in pages 120–122. This strip, when fed

through a specially constructed and very simple telegraph instrument, produces dot and dash signals on the line which are reproduced by a similar machine at the other end. The machine at the receiving station is connected to a perforator which turns out a facsimile of the perforated strip used at the sending station. This strip is then transcribed into ordinary language and delivered by the regular mail carrier, or by special messenger if desired, the idea being to send out at very low cost what might be called a *slow telegram*. It is estimated that a message mailed in New York before noon could be collected, transmitted, and delivered at its destination during the afternoon.

The expense of transporting the enormous mails between these two cities is at present very great, and much of that could be saved. Twenty-four hours in time would also be saved, and the sender would be amply compensated for the somewhat increased cost by the great saving in time. The charge contemplated is only ten cents. This would cover all expenses, and of course another ten cents would enable a similar fifty-word message to be received in New York the next morning, a total cost of twenty cents as compared to several dollars for ordinary telegrams of similar length. Many business men would naturally prefer to have their letters come in the original form of perforated strip, transcribing them at their own offices. This would insure secrecy and also hasten delivery. This service would require a specially built line, the wire or wires of which, while about the same size as those ordinarily used on the telegraph line, would be of hard drawn copper, which possesses great tensile strength and is therefore less liable to be broken down during storms, and which would also have seven times the conducting capacity of

an iron wire of similar size. With such a line the messages could be sent direct from New York to Chicago, and by means of mechanical transmission, at an enormously high rate of speed, so that ten long messages could easily be despatched in this way by a good operator in the time required to send one short one by hand.

Of course, wherever mail can be delivered between points within a few hours, as between New York and Philadelphia for instance, such a system is not called for. In the case also of private correspondence, where the difference of a day or two is not important, such a system would not be either demanded or appreciated, but the vast mass of business correspondence between large cities practically two days apart would undoubtedly seek this method of acceleration as soon as provided. Such a system would afford a much more economical method of rapid communication than the ordinary telegram. It would be possible, too, where the long distance telephone would not be considered on account of necessary cost. Only a limited number of talks can be held in a business day over the very best long distance circuit, while over an equally good circuit many hundred times as much can be sent by the enormously rapid mechanical transmission, to be used by night as well as by day, thus bringing New York and New Orleans as near together on important matters as New York and Philadelphia.

WIRELESS TELEGRAPHY

It has been known for years that an electric discharge, such as that from a Leyden jar or an electric machine, would produce electric disturbances in the form of waves

in the surrounding atmosphere. Professor Hertz constructed an instrument which was sufficiently sensitive to be affected by and to respond to such electric waves when placed at a short distance from their source; this device he called a "coherer." Quite recently a young Italian, Mr. Marconi, has taken up the study of these phenomena, and by investigation and experiment has so developed the system as to establish the possibility of wireless telegraphy, which is now being rapidly pushed to practical success and doubtless wide, if not universal, application.

In his system Marconi produces electrical discharges or sparks from a point in the air raised somewhat above the immediate surroundings. Now, when a receiver, which is adjusted to respond to a wave of the character and force which is set up by the discharge from the sending station, is located at a suitable distance, it responds to the wave, and as the waves are short or long, will correctly reproduce the signals sent. The Morse code of dots and dashes, or signals and intervals, is used, so that the sounds coming from the receiver are read and understood in the ordinary way. Of course a recording instrument by which the signals are marked upon a moving strip of paper could be employed in connection with the receiver, but in this country those machines are obsolete, and sound is relied upon entirely.

Mr. Marconi says that there is practically no limit to the distances through which the electric waves may be sent and received, and he has even now secured perfect results up to twenty miles. In 1899, Mr. Marconi reported the international yacht races from a ship to the land, a distance at one time of over ten miles, and his despatches were telegraphed to a newspaper in New York, printed, and

distributed and sold on the streets, within an hour of the time of sending the messages from the ship at sea. Such results as these in the hands of a young, capable, and enthusiastic investigator, and backed by equally enthusiastic capital, must surely produce wonderful results in the near future.

It is true that all the receiving instruments which were similarly adjusted and which were within the same radius would be similarly influenced, and all receive the same message very much as the *sounders* in an ordinary wire circuit are now actuated. The limitless variations of current which can be produced will, however, enable waves of different character to be sent, and the instruments will be adjusted to respond to different forms of wave, so that each can be actuated as desired. Mr. Tesla believes that power can be transmitted in this same manner from one high tower to another over thousands of miles of distance, even from Niagara Falls to the Eiffel Tower at Paris, France.

SPACE TELEPHONY

Public announcement has very recently been made that attempts to transmit speech by telephone through space, that is, without wires, have met with such success as to justify the belief that within the very near future speech will be transmitted through space with as great facility as telegraphic signals by the Marconi system.

ELECTRICITY ABOARD SHIP

While many people are aware, in a general way, that electric lights are employed on board ships, very few

realize the importance of this fact, or what the electric light has done for shipbuilding, and ship operating, including also ship comfort, ship luxury, and ship safety.

The writer has long held the opinion that if the incandescent electric lamp had never had any other useful application than the lighting of vessels, it would have been counted a success, and its inventor regarded as a public benefactor.

For many long years the oil room of a vessel was the danger spot par excellence. It was infinitely worse, in that respect, than the powder magazine of a war vessel. Of course, where a box of candles covered the entire illuminating outfit, the case would be simple, but it would be another matter, and a very serious matter indeed, to light one of the large modern steamships by any other means than incandescent electric lamps. Imagine the effect upon the health and spirits of several thousand persons if shut up in a huge iron hull for hours at a time with several thousand naked lights. Either the passengers or the lights would be stifled and go out after a very short period. It will be seen therefore that the incandescent electric lamp has played a very large and important part in the development of the enormous floating hotels that now cross the big seas in every direction; and this is only one feature of the case, the apparently simple matter of illumination on merchant vessels.

The importance of the electric light on war vessels is infinitely greater. Every warship is provided with circuits operating lights for general illumination and for use under ordinary circumstances, and other circuits operating lights only for use when it is desired to navigate the ship without permitting a single ray to be visible from the exterior in

any direction. These last are called battle circuits, and a ship so equipped can proceed with safety, knowing that no lights can be even accidentally displayed so as to disclose the position of the ship to the enemy. But there are other and further uses which render the application of this form of power of the utmost importance. Every large steam vessel of the present day is provided with a great number of what are called auxiliaries, that is, engines for performing work other than driving the vessel. These engines are located in different positions, such as ash hoists, cargo hoists, steering engines, numerous ventilating fans, and the like, which, when operated by steam, necessitate the installation of long lines of steam pipe throughout the ship. These pipes are always liable to leak, and in warm weather overheat the spaces surrounding them so as to make them either entirely uninhabitable or very uncomfortable. On board a ship there must be large spaces assigned to cargo and fuel, which spaces cannot be invaded by the plumber, as can one's house, whenever a pipe happens to leak. Therefore steam pipes must be carried through those parts of the ship where they will be always accessible; namely, the living rooms. Electric wires, on the other hand, can be brought together in any convenient spot where they will be accessible, and without interfering with the comfort of the crew or passengers, because they can be placed in positions altogether unavailable for steam pipes. They are not liable to be frozen, nor do they give out any appreciable amount of heat, nor do they discharge liquid of any kind under any circumstances. Consequently they offer an absolutely ideal method of transporting power about a ship, since they will allow of being bent, or even stretched to some

growing chances of collision with one of the modern floating palaces. But the danger to the larger vessel is by no means small, and some of the most magnificent steamships of their time have been destroyed in this way, so that they too are anxious to avoid collision, as the risks on both sides are too great to be willingly taken. Thankful indeed should both parties be for any provision that makes their presence known in time to avert disaster.

ELECTRICITY IN FACTORIES

In the application of electric power to mechanical uses where work is to be performed, and steadiness of operation is desired, or where the machines to be driven are too heavy to be operated by hand or foot power, and hardly large or numerous enough to justify the expense of a steam engine, a single electric motor of small size meets all requirements. This can be had of the constant speed type, which, with known conditions of service, is not liable to the variations that give so much trouble with the small steam engine. Such motors are usually on the day circuit of an electric lighting plant, and are regularly inspected and kept in order by one of the electricians connected therewith, so that the user is not required to incur the expense of an additional person to look after the motor. In larger factories, the advantage of using electric motors is equally manifest. Heretofore, it has been the plan in large workshops to instal a steam engine of sufficient power to operate all the machinery, motion being communicated thereto from long lines of shafting running in journals overhead and connected by belts to the engine. All such workshops are built with

reference to the connecting of these line-shafts, as they are called, to the central engine. This can now be entirely dispensed with and a number of motors employed to take its place. The amount of power necessary to turn all the shafts in a shop all the time is very great as compared to the work actually performed upon the products of the shop, and obviously, where but half the machines are in use, or in use only part of the time, there is a great waste of power in constantly running the shafting by which they are driven. With electric motors the shafting is divided into shorter lengths and a small motor applied to each piece or to small groups of pieces of shafting, so that any desired shaft with its machine can be operated while the others are not in use. This gives a distribution of power which is exceedingly convenient, and, a supply of current being available, incandescent lamps are often provided for the purpose of illuminating dark corners and for the still more important purpose of enabling the workmen to better see the progress of work upon the interiors of hollow constructions.

In addition, by the use of separate motors, machines and machine tools can be located with special reference to the convenience of their operation and the moving of heavy pieces of work to and from them, or a machine requiring extra power can at any time be added, with its own separate motor to drive it, without the difficulty and expense which would otherwise be incurred from being obliged to run special shafting or increase the strength of that already in place.

A further advantage of this system is that additions can be made to the buildings of a manufacturing establishment in any direction that is most economical, and much ground

can be used which would not otherwise be available, because the motors for power can be placed wherever desired, all restrictions due to line shafting and the location of the central steam engine being removed.

In the operation of one of the largest electric manufacturing establishments, the General Electric Works at Schenectady, New York, an enormous increase in its facilities recently became necessary, due not only to the great increase in the demand for electrical apparatus, but also the much larger sizes of the generators now used, so that the original shops became quite inadequate, and additional ones of greater capacity had to be provided. The steam engine by which the machinery was at first driven long ago proved too small, and to supply the increasing demand for power a power station, equipped with alternating-current generators, was constructed at Mechanics Falls on the Mohawk River, some twenty-six miles away. The generators there are operated by water-wheels at the Falls, and the current is transmitted twenty-six miles to the factory, where it is "stepped down" and distributed to the motors, most of them of the alternating current type, in different parts of the works and by which the machinery is driven. Many of the larger special machines are driven each by its own separate motor entirely independent of the others.

ELECTRICITY IN THE OPERATION OF LARGE OFFICE BUILDINGS

Very few of the tenants of modern office buildings, such as are found in New York, Chicago, St. Louis and similar cities, have any conception of the part played in

the daily economy of their office life by the electrical current. It seems very simple to utilize a dark corner by means of an electric light running all day, and also to enter a smooth and rapid elevator and learn that its motive power is electricity, but that is only the beginning. In many of the modern office buildings the system of heating and the electric power plant are so combined that the steam engine is employed only to operate dynamo-electric generators for the production of current, while the spent or exhaust steam is utilized to heat the building, for which purpose it is, even as a waste product, quite sufficiently hot to meet all requirements, except in the coldest weather, when a small proportion of fresh, live steam is added. The electricity so generated operates motors to run the elevators, furnishes lights, and is also much used to drive ventilating and exhaust fans. In all of the large buildings the foundations are very deep, and the cellars usually extend two stories below the sidewalk. This space is nowadays completely filled with machinery, to which many of the new buildings have recently added a small refrigerating plant supplying ice water on every floor. When this is combined with an artesian well, as is often the case, these buildings are complete in themselves and dependent on outside establishments for absolutely nothing except coal.

The modern hotel is similarly situated. Many of the newer ones are equipped with combined steam and electrical plants, which have been designed with the greatest possible care by engineers of the highest skill. These carry on the heavy work of the hotel in the most economical and reliable manner, and render the establishment as nearly independent of breakdowns or failure in outside sources of supply as is possible.

SIGNALLING

In Chapter XX., among the various applications of electricity, one is mentioned in which an annunciator in the office of a hotel is connected with all the rooms, so that a button in each room will, when pushed, drop a signal in the office indicating that the occupant of that room, the number of which is given, requires attention. Many of the large hotels in the United States are now equipped with a system which has devices placed in the guest rooms that do everything but think. Each room is provided with a dial upon which is a movable pointer. Upon this dial almost every conceivable thing is printed, from a bottle of ink to a bottle of champagne, and from the porter to get your baggage to the barber to dress your hair. It does not seem possible that a guest, no matter how many his wants, could possibly think of anything permissible in his room that is not to be found on this wonderful list. At the office there is a signal board with the names of all the articles on the dials in the guests' rooms. The guest moves the pointer until it is opposite the name of what he wants, then presses the button. The number of the room is first signalled to the office by the button and then the pointer, in moving back to its zero position, acts upon the circuit and transmits a signal that indicates on the board at the office just what is called for. The name of this apparatus is the Herzog Telseme.

FIRE PROTECTION

The system of electric fire signals also referred to in Chapter XX. has been very greatly improved, and there

is now for sale a form of conducting cable which is used on protection signal circuits. This wire not only transmits burglar alarm signals in the ordinary way by indicating any tampering with the circuits, and so notifying the police or the watchman, but the conductor is composite and a sensitive material is employed so that in case of a fire in any room of the building protected by this system, a rise in temperature above a specified degree will turn in an alarm without breaking the circuit, one of the component parts of the cable acting as a thermostat, of which there are a great number—several to each room through which the circuit passes.

PRODUCTION OF ELECTRICITY BY NATURAL FORCES

Much has been said in a general way concerning the vast extent of the natural forces which are neglected and allowed to go to waste all about us. Scientific men and investigators whose thoughts deal more with the future than with the present, realizing this, have pointed out many instances in which work now accomplished by coal-produced power could be much more economically performed by the utilization of sources of power not now considered available. For instance, distant waterfalls, accumulations of cheap fuel in remote places, the currents of rapid rivers, the force of the tides, and the heat of the sun. The greatest stress is usually laid upon those forms which are most difficult to handle and which would call for the expenditure of great sums of money. Nevertheless, the prophets are right. Some of their predictions are already fulfilled. Many more of these things will come

to pass in time, although the expense will probably be too great for individuals and will necessitate co-operation or centralization of capital. At present, however, simpler methods are still available in plenty. Cheap coal enables the manufacturer to retain his individuality and to operate separately and successfully in many parts of the country. Where that is the case, and so long as that continues to be the case, existing conditions will prevail, as a general thing.

The discovery of natural gas revolutionized some industries and utterly changed the conditions in some of our manufacturing cities, particularly in Pittsburg, from which place the dirt and smoke, due to the enormous amounts of bituminous coal used in the treatment of iron and steel, disappeared during the reign of natural gas a few years ago. Unfortunately the gas proved to be mostly an accumulation, and although in immense quantity, it was finally used down to the natural supply, which, while regular and continuous, was far below the demand to which its great utility and convenience had given rise. So the bituminous coal came back again. Natural gas, however, during its short but brilliant career, established a record that demonstrated the great superiority and economy of fuel in that form, and there is no doubt that, having the system of piping which was specially put in and used for the conveyance of natural gas as fuel, it is only a question of time when those pipes will be connected to the nearest supply of cheap coal, from which cheap gas will be produced, and the smokeless age will begin. There would then be no failure in the supply of gas, as it would be produced to accord with the demand, and the hauling of millions of tons of coal will become unnecessary. Naturally, the railroads will oppose this now, but

as their business grows in other lines, they will become the most willing supporters of such a plan.

During the past few years much has been accomplished in the utilization of remote waterfalls. Even those of small quantity but steady supply from the melting snows in the mountains are collected and piped for miles to the lowest available point and there the power house is located.

It is remarkable how wide a range of hydraulic conditions are successfully met by combinations of the water-wheel and the dynamo. In the West we have heads of water of as much as 1,000 feet driving impulse wheels direct connected to generators. In the East we have heads of as low as ten feet driving turbines with vertical shafts connected to generators through mitre gearing. At the present rate of installation, we may expect that in the course of the next few decades most of the great rivers of the world will be harnessed to dynamos and will distribute power to distances of many miles. Any one who visits these water power installations will be struck by the simplicity of the apparatus and system. The generators are usually connected directly to the water wheel shafts, and unless the distance of transmission is over, say, fifteen miles, the line wires may be connected directly to the armature terminals. Step-down transmissions do the rest. As the distance of transmission increases and the electric pressure is raised, the two principal and ever present obstacles acquire increased force: they are the insulation difficulty on the one hand and protection from lightning on the other. The higher the pressure employed the more closely does the electric energy delivered to the line conductors resemble miniature lightning in its propensities, and the greater becomes the difficulty of keeping out at-

mospheric electricity and keeping in the electricity generated. So successful have these lesser attempts been, that finally the capital was obtained to undertake the difficult and costly work of cutting the tunnels and building the great generators that would make it worth while to direct part of the waters of the Niagara River at the Falls to the operation of water-wheels for driving dynamo-electric generators to produce current of high tension for commercial distribution, for power and general purposes. This has now been fairly begun, and upon the scale which such a work deserves.

NIAGARA FALLS

THE utilization of the enormous water-power which for generations has gone to waste over the Falls of Niagara has for many years been the most prominent and obvious proposition, and one of which it was popularly expected that electricians would take advantage just as soon as it could be done on a safe commercial basis. Very naturally the Falls of Niagara, being so well known, have been referred to by every speaker and every writer on the subject, and this natural source of power has seemed to embody all the vast possibilities of the electrical transmission of power at nominal cost. Undoubtedly it was much the most spectacular performance of any that could be attempted, and at the same time one which would become most readily known to the world at large. The work to be actually done in order to make it possible to place and operate water-wheels at Niagara, was to cut a canal or raceway at one side of the river to a point below the Falls, the canal being just large enough to convey the

desired amount of water. At the end of the canal a large, deep well called the wheel pit, was sunk in solid rock, and at the bottom of this pit the turbine wheels are located. The pit is filled with water from the canal which can only escape downward through the wheels, thereby operating them, and the dynamos, one of which is connected to the upper end of each wheel shaft. These shafts extend up, through the water in the wheel pit, to the power house above it in which the generators are located. From below the pit a tunnel had to be excavated, also in the solid rock, to carry off the water from the wheels, the mouth of the tunnel or waste-way being just above the ordinary level of the water in the Niagara River below the Falls. When, and in proportion as the gates of the turbine wheels are opened, the water from the wheel pit passes through them, imparting motion to their rotating parts, and escaping thence downward into the tunnel, and out to the river. The head of water, often referred to, is the difference between the level of the canal, taking the water from the upper part of the river above the Falls and the tunnel below the Falls which discharges the water after it has gone through the wheels. The generators connected to the turbine wheels are of the alternating-current type and were at the time of their installation actually the largest in the world, being calculated to and delivering regularly and steadily 5,000 horsepower in the form of electrical current of high tension.

The current from Niagara generators is supplying almost every kind of electrical industry. It is transformed into direct current at constant voltage and at variable voltage. It is transformed as alternating current to a low voltage, either constant or variable, and to a high voltage for

transmission from two phases to three phases. The current is used for developing mechanical power which replaces steam engines, does miscellaneous work, such as heating and welding, and operates street railways. It is used for lighting and for ordinary heating. In the new processes it is used for its electrolytic and heating effects. Heating is produced both by direct passage of the current through materials—sometimes in liquid, sometimes in solid form—and by the electric arc.

The important enterprises at Niagara are new, and include the manufacture of carborundum and certain chemicals. The processes of production are among those which electricity has recently given to the arts. They are large consumers of power, and their commercial practicability depends upon its cheapness. In ordinary manufacturing industries the cost of power is a small percentage of the cost of material and labor, and the power is used only a small part of the day. In the industries at Niagara the cost of power is the vital element, and while on the one hand their continuous operation makes them ideal customers of a water-power plant, on the other hand they are significant omens of the advance in industrial methods which is made possible by abundant and cheap electric current. A diagrammatic representation of the different forms of distribution is seen in Fig. 99.

The work already accomplished at Niagara Falls is stupendous. There are now five 5,000-horsepower generators constantly in operation, each one driven by a separate water-wheel and delivering alternating currents, part of which is used in the immediate vicinity, and part sent over transmission lines which as yet carry it only as far as Buffalo, twenty-six miles distant, where it is trans-

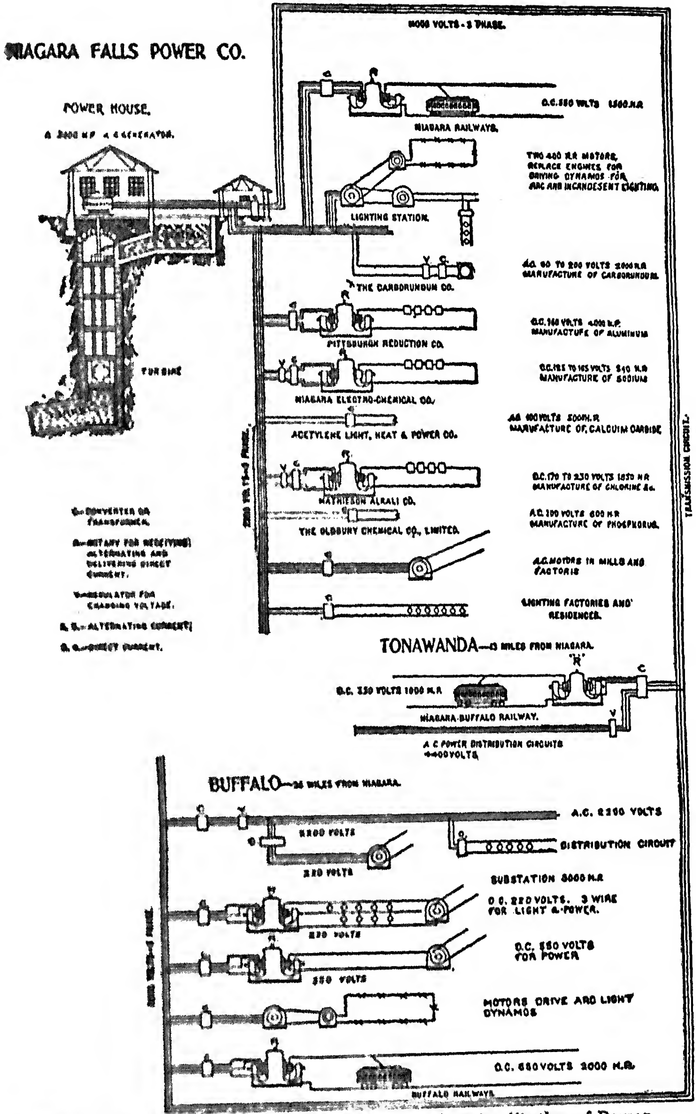

Diagram of Circuits from Niagara Plant, Showing Application of Power

FIG. 99.

formed, as stated, into currents of different potential, according to the use to which it is to be put, and distributed throughout the city over lighting and power circuits. The value of cheap power as supplied by the Niagara plant is already so fully appreciated that the capacity of the plant is now being increased by the addition of 10,000 horsepower to the original 25,000. The future of Buffalo is regarded as very bright in view of this unlimited and reliable source of power, which is rented at fixed rates, so that a manufacturer will know exactly what it will cost him the year round, and all the trouble, dirt, dust, and disorder attending the hauling of coal through the streets, its delivery, storage, and handling, is avoided. Surely it cannot be long in that city before electric heating and cooking are added generally to the list of its applications.

A similar work is being carried on on the Canadian side of the Falls, and the adjacent cities in Canada will also participate in the advantage shown by American skill and enterprise to be in every way successful. It is only a question of time when the currents generated in Niagara Falls will reach further points, such as Rochester and Syracuse, and doubtless Albany and New York. As we have seen, it is possible to step up, raise the tension of, the current, it being of alternating character, by convertors placed along the line, and transform it into current of still higher potential, if necessary, in order to enable it to traverse many more miles of conductors without excessive loss or the employment of conductors of too great cost. At present, however, there stands in the way of this extreme long distance transmission, Niagara to New York City, the steam engine plants in operation. The electrical industry must grow somewhat slowly in its application to new factories and machine shops

until its economy of operation reaches a point which will justify manufacturers in discarding their present engines and purchasing electric motors to take their places. During the past few years many waterfalls have been utilized in the same manner as the Falls at Niagara, particularly those originating in the wild and almost inaccessible gorges of the Rocky Mountains. Here the water from the melting snows is collected and brought by large and immensely strong steel pipes to points where the greatest power can be realized therefrom. In these cases the supply is practically constant, but the quantity small. The source, however, is high, and by piping the water to the lowest available point, an enormous head is secured, so that a small quantity of water develops an enormous power when used to operate water-wheels or engines of special construction. These water engines are connected to alternating-current generators, which deliver currents of very high potential, that is, great force, to long lines whereby the current is transmitted many miles to neighboring towns, mines, etc., where it is used for hauling, lighting, hoisting, operating ice-making plants, and many other industries, mostly new, and many of them practically out of reach of the ordinary steam engine on account of the difficulty and cost of procuring fuel.

The important details of a few of the larger long-distance transmission plants will be found in the following paragraphs, and from these data a fair idea can be obtained of the extent to which this branch of the art has already been developed, and at the same time also of the degree of technical skill both in plan and in execution which has been attained by the electrical engineers of the present day. These plants represent a great deal of actual expended cash,

which would not have been forthcoming unless the ability of those in charge to successfully carry out the various plans had been sufficiently demonstrated.

The Big Cottonwood Plant (Utah) horsepower is developed from a waterfall in the Big Cottonwood Cañon, which is piped to the power house and used to drive four 600-horsepower Pelton wheels each directly connected to one 450-kilowatt triphase alternating-current generator, giving current at 2,000 volts, 60 cycles per second. This current is raised by step-up transformers, at the station, to a pressure of 10,000 volts, and is then sent over the transmission line fourteen miles to a sub-station at Salt Lake City. At the sub-station the pressure is reduced by step-down transformers to 2,000 volts, at which pressure it is supplied to the secondary system extending about the city, in which it is further reduced for domestic use by local transformers, as may be required.

Ogden (Salt Lake City) Plant. A dam across the Ogden River, six or seven miles from Ogden, provides a large storage reservoir, the water from which is carried through a flume to the power house five miles distant. The head at the power house is 450 feet, and the flume can convey sufficient water to develop about 10,000 horsepower. Five 750-kilowatt General Electric generators of the triphase alternating-current type are now in operation, each driven by a Knight water-wheel of 1,200 horsepower directly connected. Step-up transformers raise the voltage to 11,100 volts and deliver current to the transmission line extending thirty-six miles to Salt Lake City. At Salt Lake City step-down transformers reduce the pressure again to 2,300 volts, at which it is distributed to the city supply system The transmission line in this case consists of two

circuits each, comprising three bare copper wires, supported upon porcelain insulators carried by a pole line. These two circuits have been experimentally connected so as to make one circuit of seventy-three miles; also the pressure was stepped up to 30,000 volts, and at this very high potential 1,000 horsepower was transmitted over this seventy-three mile circuit with a loss of only 9 per cent of the current on the wires and 4 per cent in the transformers. This exceedingly interesting and important demonstration shows what can be done when the necessity arises. Of course, when this experiment was made the insulation was at its best, the weather fine and the air dry; these perfect results probably could not have been secured during a rain storm. Therefore, for continuous operation at such a pressure, 30,000 volts, extra precautions would have to be taken and special insulators would have to be placed all over the line in order to prevent such a breakdown as would be caused by the current escaping from the line to the earth.

Portland, Oregon. The transmission plant supplying this city is located twelve miles away, and is designed for an ultimate capacity of 12,000 horsepower, of which 4,000 is now in use. Current is generated in large General Electric triphase generators by direct-connected Victor turbine wheels of 500 horsepower each, the current being sent to the transmission line at a pressure of 6,000 volts. This current is stepped down at the receiving sub-station at Portland to 1,000 volts for delivery to the secondary system, from which it is supplied to consumers. Part of it is also sent through rotary transformers and thereby converted into continuous current of 500 horsepower pressure for use in the street railway system

St. Anthony's Falls, Minnesota. From the power house located at this point circuits run to three sub-stations, two in Minneapolis and one in St. Paul, the distance ranging from two to ten miles. The water-wheel plant consists of ten turbine wheels of 1,000 horsepower each. Of these, seven are direct-connected to seven 700-kilowatt triphase alternators, furnishing current at 3,450 volts; the remaining three drive three 750 direct-current generators furnishing current at 600 volts. The current from these several generators is sent to the sub-stations, part in the form of alternating current and part in the form of direct current, the latter being used for the street railway systems of the two cities, and the former, the alternating current, being stepped down to supply the lighting systems.

California has at the present time several large installations, among which may be mentioned plants at the Blue Lakes, which comprise three 700-horsepower Pelton wheels under a head of 1,040 feet, operating a like number of 450 kilowatt Stanley diphase inductor generators delivering current to the transmission line at 2,400 volts pressure and 60 cycles per second. This pressure is raised by step up transformers to 11,000 volts. The line is thirty-nine miles long, extending from the power house to the City of Stockton.

Folsom, California. This station has four pairs of 30" McCormack turbine wheels, 1,200 horsepower each, coupled to 750-kilowatt General Electric three-phase generators, giving current of 60 cycles at 800 volts. This current is stepped up at the station to 11,000 volts, and sent out at that pressure over the transmission line from Folsom to Sacramento, a distance of about twenty-four miles. The receiving substation at Sacramento is provided with transformers designed to step down the current and divided into three

kinds, one for domestic lighting, one for electric railway use, and the third for circuits requiring current of high tension.

Fresno, California, is supplied from a plant thirty-five miles away in the mountains, where under a head of 1,400 feet of water a number of Pelton water wheels are operated each directly connected to a General Electric three phase generator. The current is stepped up at the power station and sent over the line to Fresno at a pressure of 11,200 volts. In the sub-station at Fresno this current is stepped down to three different pressures as in the case at Folsom, which allows of a local distribution and use corresponding to a triple distributing system, with low, medium and high tension current for use as required.

Helena, Montana, is supplied from a power house about ten miles away, where 4,000 horsepower is developed by Westinghouse alternators operated by the American turbine wheels. The current is stepped up at the power station to 10,000 volts, sent over the transmission line to and stepped down at two sub-stations, in this instance partly through rotary converters which supply the street railway system, and partly through static transformers which supply current to the ordinary distributing system of the city. In this, as in several cases, the current is used directly to operate incandescent lights, the arc lights which are required being produced by separate arc light generators driven by alternating current motors located at the sub-station.

Montmorency Falls, Canada. A transmission plant has been constructed which transmits alternating current at a pressure of 5,000 volts over a line eight miles long to the sub-station in the city of Quebec, where the current is stepped down for distribution through the city. This station is equipped with turbine water wheels 1,200 horse-

power, connected directly to Stanley diaphase generators of 600 kilowatt capacity, and which, in view of the comparatively short distance of transmission, deliver the alternating current direct to the line at 5,200 volts, thus avoiding the loss incident to the use of the step-up transformer, which though small is worth saving.

The city of Montreal, Canada, is supplied from an electrical power plant at Chambly, sixteen and one-half miles away on the Richelieu River. In this plant the current is generated at a pressure of 12,000 volts with 66 cycles per second, which is sent directly to the transmission line and is stepped down at the receiving end in Montreal for city distribution. This is perhaps the highest potential at which current is now generated, and it is interesting to know that 12,000 volts direct from the machine to the transmission line, without the aid of step-up transformers, is not only a possibility, but an everyday operative arrangement.

It has long been proposed to use the immense force present in the rise and fall of the tides to produce power through a suitable apparatus, and this is undoubtedly practical, but other and more convenient means, such as those just referred to, will be utilized to their fullest extent before this method is availed of, because streams of water are more easily controlled and handled than tidal waters, and at much less cost. Furthermore, the liability of damage by storms must always be taken into consideration in connection with tidal machinery.

Last of all comes the power of the sun. The human mind can only imagine of what that is capable, but we must find our way through many less daring attempts before we are prepared to avail ourselves of this the greatest of all the forces known to man. Great systems of storage

of energy will be required in order to have a reliable and sufficient quantity of sun-power in some form always available so that the desired work may be performed by night as well as by day, and whether the sun shines or not. There will be exceptions, as in those instances in which sunshine and work go together, for example, in harvesting, and some other agricultural operations.

It is interesting to know that currents of rapid streams have been adapted to industrial purposes. Forty years ago the writer saw the floating mills on the Danube. These are house boats anchored in the stream and provided with a large paddle-wheel at one side to the axle of which the simple form of mechanism for operating the well-known millstones is connected, precisely as in the old-fashioned country mill, the power being supplied by the action of the current on the paddles of the wheel at practically no expense whatever. The grain to be ground and the resultant product is conveyed between the shore and the mills in boats.

With bituminous coal all of it is used, both lump and slack, the different varieties being suited to particular purposes. The entire product of many mines is transformed into coke on the spot and sent to market in that form. This coke is far richer in carbon than is ordinary gas house coke, and is particularly desirable for use in smelting furnaces, since it produces a greater heat than can be obtained from the coal. With anthracite coal, however, the case is somewhat different. This variety is always sent to market in the form of lumps, large or small, but free from dust or slack, and this is necessary in ordinary use, because of the amount of air needed for the combustion of anthracite and the difference in the methods of

firing. In the anthracite coal regions, therefore, there have accumulated enormous piles of what is called culm (slack) which comprise the finer particles broken from the large lumps as they are run through the crusher in order to reduce them to marketable size. These culm piles contain millions of tons of good fuel which will, undoubtedly, be utilized in the not far distant future in the production of electricity and cheap gas, but electricity will come first, because it stands first and foremost among all the discoveries of man in its capacity of being transmitted, or, in other words, in its capacity for acting as a vehicle to transport power over long distances with the least known loss.

There *is*, as yet, no other way of transporting a thousand horsepower a hundred miles and having any considerable portion of it at the other end. You might compress air into vessels and transport them, but the cost of transporting the vessels in any known way would consume the value of the power. You could lay a pipe and force gas through it, but, unlike electricity, after having produced the gas, you would have to furnish powerful pumps in order to propel it (the gas) through the pipe. The cost of this would absorb much of the value of the gas and there would also be great loss from condensation. So that in considering the application of distant sources of power to great works and operations, electricity furnishes the only practicable means yet actually tested, and the cost of which and the conditions under which it can be applied are definitely known.

GAS ENGINE-DRIVEN ELECTRIC GENERATORS

For many years engines operated by the explosion of compressed charges of illuminating gas mixed with air

have been employed to meet special conditions, but for a long time they were regarded as expensive luxuries only to be used under very exceptional circumstances. The Otto engine is the best known of the earlier types, and many thousands of these are in use. For years, however, it has been accepted as a fact that the gas engine was restricted to small sizes, and that, therefore, it was not practicable to construct it in a manner such as would adapt it to large installations and develop the greatest possible economy of operation and maintenance.

The engine department of the Westinghouse Manufacturing Company, of Pittsburg, believing differently, has devoted a great deal of time and money to the development of this species of engine and to the construction of larger sizes, so that they have, at the present time, several 650-horsepower gas engines in operation, one of which has been running for two years. This company is also, at the present time, engaged in constructing two of a series of gas engines of 1,500 horsepower each, all to be employed in driving electric generators. Mr. Westinghouse is authority for the statement that "the advantages of the use of gas engines can be best appreciated when it is understood that if a gas company were to supplant the present gas illumination by an equal amount of electric light, obtained from gas-driven dynamos, it would have left for sale, for other purposes, over 60 per cent of its present gas output." It is further announced that by the use of producer gas, that is, a fuel gas much cheaper than that made for illuminating purposes, a horsepower can be developed in a gas engine at the rate of one pound of coal per horsepower per hour. Very few steam plants can be operated on double that quantity.

In taking up the various methods of producing current for general distribution and use, the most important consideration is, how can it be delivered within the desired territory at the lowest cost? Fuel, both for heating, operating steam boilers and in the arts will undoubtedly be used in the form of coal for a long time to come, but that which is transported over any considerable distance will be only the very best. The new methods of transmitting power will very soon make it unprofitable to transport cheaper grades. The utilization of the lower grades of coal, to which may be added the many million tons now classed as refuse, of no commercial value, indicates the opportunity for an enormous industrial economy. This low grade fuel will yield a much larger proportion of gas than its value as fuel would indicate, and that gas would be as good as any for the operation of large gas engines. It may be that such engines, combined with large dynamo-electric generators, will afford the means for converting this material into electricity for lighting and heating whole cities, within a radius of a hundred or more miles. Furthermore, as we have seen, gas is a much more convenient fuel than coal of any kind. Large quantities of it could readily be transported over long distances if accumulated in holders under sufficient pressure to overcome the friction of the pipes, and cities could be supplied in this way at a greatly reduced cost. More gas is used to-day than before the electric light was introduced. The general illumination is better. In the opinion of the writer, electric lighting will increase steadily and gas lighting will decrease, but the gas will not disappear; it will be used in steadily increasing quantity. The things that will disappear are the coal cart, the coal hole and the coal-fired furnace for domestic heating. The two former will become

obsolete, and the hot-air furnace, as we understand it to-day, be supplanted by the simplest kind of a sheet-iron heat generator operated by a gas flame and actually capable of the automatic regulation so often sighed for, but apparently unattainable with solid fuel.

ELECTRICITY DIRECT FROM HEAT

THE ultimate production of electric current direct from coal, that is, from heat produced by the consumption of fuel, has been for years the dream of the electrician and has occupied very much the same position electrically as has the philosopher's stone by which base metals were to be changed to gold. Truly anything that would transform coal into electric current without the intervention of machinery, the steam boiler, steam engine and dynamo-electric generator at present necessary, would be of equal value to humanity, provided this could be accomplished in a simple way. Some progress, however, has been made in this direction, and while the results are not yet such as to enable this method of generation to compete commercially with the dynamo electric generator and its driving engine, they undoubtedly point to higher things and must serve to very greatly encourage their discoverers.

Starting with the known fact that when a lodestone or a magnetized iron bar was heated to redness it lost its magnetism, Dr. G. Gore, in 1868, succeeded in generating a current in a coil of wire by the alternate heating and cooling of a magnet placed in inductive proximity thereto. Dr. Gore's apparatus consisted in a coil of copper wire through [illegible] which passed an iron wire which was kept

magnetized by contact with a permanent magnet, the arrangement being such that the iron wire formed a core for the coil of copper wire. The iron wire being heated and cooled, its magnetism rose and fell, and current was correspondingly generated in the surrounding coil of copper wire. Numerous other experiments have been made, all of which prove that a magnet capable of exciting current in a surrounding coil of copper wire would be demagnetized by the application of heat. The great question, however, was, and is, how to apply this heat in such a way as to produce a sufficiently rapid change of temperature to generate current enough in the coil of wire to be of any service.

About the year 1887, Mr. Thomas A. Edison introduced his pyro-magnetic motor. In this machine the armature to be acted upon was constructed in the form of a rotatable bundle of small tubes of thin iron, which were placed between the poles of a large magnet. Highly heated air was then passed through part of these tubes, while part of them were kept cool. This caused the magnetism to be stronger in the cool parts of the armature than in the highly heated parts, so that, instead of standing still between the poles of its field magnet, it (the bundle of tubes) was rotated between them.

A motor embodying this principle was constructed weighing about 1,500 pounds and calculated to develop about three horsepower. This motor worked successfully, but notwithstanding the correctness of the theory it has not yet been ascertained how to overcome the mechanical difficulties sufficiently to bring this machine within the field of competition with the dynamo-electric motor in its present state of perfection. The trouble seems to be

that under no circumstances can the tubes of the armature be heated and cooled often enough to make the discovery valuable. Mr. Edison finds that 120 times per minute is the limit, and this is not rapid enough for commercial service.

Some three years ago, during 1896 and 1897, Mr. Harry Barringer Cox engaged largely in the manufacture of a thermo-electric generator which was put upon the market for domestic use, being calculated for operation by an ordinary gas jet. By this means current could be generated in the house for domestic use, as for operating a fan or sewing-machine motor. It was planned also to operate incandescent lights, although, already having the gas in the house, it was very unlikely that any one would care to instal an electric-light generating apparatus to be operated by means of the gas when they could use the gas direct for the production of light. However, the apparatus produced by Mr. Cox was in a small and convenient form, and would undoubtedly produce current direct from the application of heat. This apparatus contained a thermo-pile; that is to say, two different metals were combined so that when one of the joints between them was subjected to heat an electric current was generated between them. The potential of currents of this description has always been very low, but in the case of the Cox generator it is understood that the mechanical difficulties are great, although the probabilities are that they could have been completely overcome had there been a sufficient demand for such an apparatus.

Another notable recent achievement in this line was that of Dr. W. W. Jacques, of Boston, who, about the same time, 1897, produced his thermo-carbon cell, in which by the combustion of carbon, in the presence of a strong

alkaline solution and a current of air, a current of electricity is set up.

His apparatus, as embodied in a patent, consists of a closed furnace, which heats an iron pot about six inches in diameter and two feet deep, which is filled with caustic potash or soda, the alkali being kept in a melted state by the application of heat. In this melted alkali is suspended a rod three inches in diameter and twenty inches long, made of coal compressed into sticks of the above size and baked so as to expel the included gases. This forms one plate or electrode of the battery, and is the consumable element.

In order to accelerate the action of the battery a supply of air is to be forced through an iron pipe, which terminates in a rose nozzle. Thus the air keeps the melted hydrate in constant agitation and at the same time supplies oxygen, which Jacques claims is necessary for the chemical action. With a cell of this size a current of 150 amperes at an E.M.F. of one volt is obtained.

A test made on a battery of 100 cells, each twelve inches deep and one and one-half inches in diameter, showed that thirty 16-candlepower lamps were maintained for eighteen and three-quarter hours at full incandescence, the average E.M.F. being 90 volts, current 16 amperes, consuming eight pounds of carbon in the pots, to which, in counting cost, must be added the carbon consumed outside the pot to heat it.

As in the case of Mr. Cox's heat generator, there is no possible doubt that the current is produced by heat in Mr. Jacques' apparatus, but in this instance also the current is of very low potential, and the work does not appear to have amounted to much more than that of a very interesting

laboratory experiment; because it must be remembered that with these thermo-generators no form of regulation appears to be possible except that of graduating the heat, which method is slow at best. Then, again, they have only been tried in small sizes for which there is no particular demand. When, however, thermo-generators are constructed on such a scale that a big fire of cheap fuel can be made to produce a large volume of current, even supposing it to be at low tension, then they will be of paramount importance. Undoubtedly, the combination of dynamo-electric generators with water wheels will for a very long time prove one of the most economical sources of electric current, but a thermo-generator plant located in the midst of the culm piles of the coal regions, if only reasonably economical, would undoubtedly displace all mechanical means and be used to convert vast masses of what is now regarded as a nuisance, into electricity, which, as we have seen, can be raised in pressure for transmission as far as desired, and then lowered at the point of consumption. Such a system as this might be expected to be uneven in its action as compared with the present accurately regulated machinery. This difficulty can be overcome by supplying the low tension current from the thermo-generators to a storage battery of ample capacity, the battery being discharged through the proper converter and the current sent to line in a steady, evenly regulated flow; steadiness of action being one of the most valuable attributes of the storage battery. The thermo-generator promises to be a large, heavy construction; the storage battery we know to be such. When combined in operation as just proposed, these objections will disappear, a few tons more or less of iron and lead and brick and mortar being of no importance. The fact that

these two elements can be made to co-operate by means of a shovel to convert what is now useless rubbish, into power, in the form of electric current, is the all-important consideration which will affect the health, comfort and prosperity of future generations.

THE X-RAY

A SIMPLE description of this, the most wonderful discovery made in connection with electricity and the most recent, seems a fitting conclusion to the present review. As is usually the case, experimenting had been going on for many years in connection with the apparatus which is now used for the production of the X-Ray, so that a short glance backward is justifiable.

Professor Faraday, about the year 1830, made many experiments in connection with electric discharges within rarefied gases. Geissler, following Faraday, improved the tubes used by him for containing the rarefied gases, sealed permanent platinum electrodes into them, and increased the degree of rarefaction of the gases within the tubes. He also experimented with many different gases, and worked out some very beautiful color effects for the production of which the Geissler tubes are still manufactured and used.

In the year 1879 and subsequently, Professor William Crookes published a series of remarkable papers upon Radiant, or, as he preferred to call it, a Fourth State of Matter, these publications disclosing great advances in the study of the action of electric discharges within rarefied gases. Professor Crookes demonstrated many things, the probabilities of which were suggested by Faraday, and there is no doubt that he produced X-Rays without knowing it. Anyway he

greatly improved upon the Geissler tube and brought the tube in which the X-Rays are now produced to such a state of perfection that that part of an X-Ray apparatus is always referred to as the Crookes tube. This consists of an exhausted glass bulb similar to that of a large incandescent electric lamp, through the sides of which project two or more platinum wires carefully sealed into the glass. The inner ends of these wires are some inches apart in the interior of the bulb, and are provided with small electrodes or deflecting plates usually of platinum or aluminum. Two of the wires are used at a time, their outer ends being connected to the two conductors extending from the source of current. The circuit is thus completed to the tube, within which are the electrodes, the ends of which are separated and across which space the current must jump to return to the source.

The X or Unknown Ray was discovered during the year 1895, by Professor Wilhelm Conrad Roentgen, of Wurtzburg, Bavaria. The ray is in itself invisible, but can be felt and located by persons familiar with its use. Professor Roentgen was experimenting with several Lenard and Crookes tubes and had one of the latter in action inside of a box in a dark room. Now, it so happened that some fluorescent material was on a piece of paper that was lying near the box, and this material glowed visibly. Professor Roentgen looked for and found the cause, and the X-Ray was discovered. This led to the production of X-Rays in such quantity that experiments could be freely carried on, and these very soon resulted in the making of photographs and the application of the ray for surgical purposes.

To make ocular examination of concealed objects, such as the bones of the human body, it is necessary to place a ray producing bulb on the opposite side of the body to be

examined, and to then catch the rays coming through the body in a device for rendering them practically visible and called a *fluoroscope*. This device is usually in the form of a pyramid-shaped box having an opening at its apex, and is held before the eyes of the observer like a stereopticon, when the shadows cast by the relatively opaque portions of the body through which the X-Rays are passing become patterned upon the screen of the fluoroscope and practically show what is being sought.

The fluoroscope is a funnel-shaped or pyramidal box of wood or cardboard with an opening at the small end shaped to fit the upper part of the face, including the eyes of the observer. This box is light-tight, and its lower widest end is completely closed by a thin slab of wood or other material easily pierced by the ray, and it is the inner side of this end piece which is coated with fluorescent material, as barium-platino-cyanide or tungstate of calcium, the two best materials for the purpose, although many others can be used. In the absence of the X-Ray nothing is visible in the fluoroscope. On looking into it when exposed to the ray the entire lower end or screen is brightly illuminated by the fluorescence developed by the X-Ray in the material with which it is coated, the effect resembling the appearance of a ground glass window at night with a good light behind it. If, now, the hand be held up against the outside of the screen, the large end of the fluoroscope, the X-Rays will pass through everything except the bones so readily as to illuminate the fluoroscope just as though the fingers were not there, except in those parts covered by the bones, through which the X-Rays do not pass so readily, so that those parts of the screen *remain* dark, thereby showing the outline or shadow of the bony structure of the hand. Sim-

ilarly, if a lead pencil were held up in front of the screen, a thin black line only would be seen, this line representing the lead. This is due to the fact that the rays pass through the wood of the pencil so easily as to illuminate the material of the screen covered by the wood of the pencil just as brightly as the rest of it, consequently the wood is not seen.

X-Rays are produced by the passage of currents of very high potential between the separated inner ends of wires contained within a glass bulb from which the air has been almost completely exhausted. The ends of the wires in the bulb are provided with small metal plates which are set at such an angle as to throw or deflect the X-Rays outward through the sides of the glass bulb in the desired direction.

The apparatus necessary to produce the ray comprises a source of current, which may be a battery, and a powerful Ruhmkorff (induction) coil (referred to under Distribution of Current). The battery is connected to the primary of the induction coil and its current interrupted with great rapidity and distinctness, producing a rapid succession of alternating currents from the secondary coil, which is so proportioned that the currents flowing therefrom shall be of small quantity but very high pressure. The pressure or intensity of the secondary currents is approximately estimated by the distance said currents will jump through the air between separated terminals. With the X-Ray apparatus induction coils are used of such enormous power as to be able to produce even a 12″ spark, although a spark or flash which will jump across between terminals separated by from four to six inches will ordinarily answer. These high-tension currents are led directly

to the terminals of the Crookes tube, and, in jumping through the space between the electrodes or deflecting plates of the ends of the separated terminals within the bulb, the X-Ray is developed.

Strange though it undoubtedly is that this wonderful form of light, for it is a light, is invisible to the eye, it affects a photographic plate like any other light. The time required to make an X-Ray picture or radiograph depends upon the supply of X-Rays, and has been steadily diminishing since the original discovery by Professor Roentgen. A photograph can now be taken in a minute or so instead of requiring half an hour or more, as in the beginning. If any one were told that a man could have a photographic plate tied to his back, the plate being inside a regular light-tight plate holder, and then stand up for a couple of minutes in front of a little glass bulb filled with a pale sickly-looking light, and that that plate could then be taken from the holder and developed in the usual way in a dark room and show a photograph of that man's insides, he *could not* believe it. It is so utterly beyond any conception of mortal mind as to be a clear case of seeing is believing. We see and we know. We know that the X-Ray exists, because it makes photographs and because of the fluorescent screen, but how long it has existed and how often it has been produced we do not know, nor do we know what other extraordinary properties of high-tension electric currents are now waiting to be discovered.

The ease with which the X-Ray passes through the different materials seems to be learned only by experiment. It is doubtful whether any material will absolutely stop the rays, but a thick sheet of lead seems to offer the greatest obstacle yet discovered. A book of a thousand

paper does not obstruct the X-Ray to any noticeable extent and an observation can be carried on through a thick pine board without difficulty. It is, in fact, much easier to mention the relatively opaque bodies than to catalogue those through which the X-Ray passes without difficulty. Speaking generally, it may be said that bone, glass and some metals, particularly lead, are relatively opaque to the X-Ray, while wood, leather, paper, water, tissue, carbon, stone, etc., are transparent, that is, offer practically no obstacle to the passage of the ray therethrough. The X-Ray can be focused within the bulb, but from there it seems to travel with extraordinary speed and in straight lines. A photographic lens is of no use whatever in connection with it, because the rays pass straight through, and are neither reflected nor refracted. A photograph taken by shooting the rays through an object on to a sensitized plate is always of the same size as the object, the only way of reducing being by rephotographing. One use of the X-Ray has been to demonstrate that a most wonderful thing had been in existence for a long time without any one knowing it, and to encourage investigators in the belief that other and more wonderful things are only waiting to be discovered. Its practical use at the present time seems to be as one of the greatest aids the surgeon could possibly have, and it is to be hoped that the time will come when the X-Ray apparatus will be accessible to the poorest in every city and town. There could be no better school for the student than attendance upon such apparatus, and the patient could see for himself when a broken bone was well mended. Then we might also expect an end to the horrors of vivisection.

While this wonderful unknown ray is in itself invisible,

it travels with great rapidity, maybe further than we think, and absolutely unhindered by any such trifles as storm or fog. The future may see it applied to light-houses, for if the rays could reach to the horizon, an approaching vessel provided with a fluorescent screen, as by painting the deck-house with fluorescent paint, would catch some of them, and by a known system of signals, for instance the wireless or "*space telegraph*," might be able to ascertain her position and be saved if in danger.

Development is constantly going on in the electrical art, but much of it is necessarily of a detailed and technical character, the effects of which are more apparent in the diminished cost of new installations than what is seen by the public at large, for which reason the writer has omitted mention of many things as of no general interest, and while he may have generalized on some subjects, it is because a technical explanation would be foreign to the scope of this work.

THE substance of the foregoing has been drawn from the accounts published as the various subjects have been brought forward; but the present writer desires to acknowledge courtesies extended to him in the matter of data and information by the General Electric Company, the Westinghouse Company, and by his friend, Mr. T. Comerford Martin, editor of the "Electrical World and Engineer" of New York City.